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NAVAL RESEARCH LAB WASHINGTON DC M A FRY ET AL.
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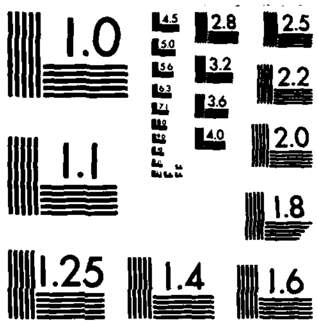
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5.6
6.3
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

(2)

NRL Memorandum Report 5571

Priscilla Calculations and Comparison with Data

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**Science Applications International Corporation*
McLean, VA 22102

May 30, 1985

This research was sponsored by the Defense Nuclear Agency under Subtask N99QAXAI, work unit 00018 and work unit title "Missile Systems Erosion Hardness."

NAVAL RESEARCH LABORATORY
Washington, D.C.

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The nuclear event PRISCILLA has been modeled with the FAST2D Flux Corrected Transport code. Three calculations were performed to study the effects of the thermal layer along the ground and the entrained dust. Comparison between the experimental data and the calculation that includes both dust and the thermal layer show good agreement. Accurate modeling of the thermal layer and inclusion of the dust are required to simulate the precursor near the ground surface. New complex shock structure above the ground surface has been discovered.

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CONTENTS

PRISCILLA CALCULATIONS AND COMPARISON WITH DATA

I. Introduction

The nuclear test PRISCILLA was performed as part of the Plumbbob series of tests in the summer of 1957. Four objectives were at the center of the
The four main objectives were to:
program: (1) obtain overpressure annd dynamic pressure as a function of time and distance; (2) document the formation and history of the precursor waveforms; (3) determine the applicability of scaling laws; and (4) determine the validity of the pressure-distance curve in the low-pressure
Since
region.[1] These objectives were achieved, ~~and as a result,~~ it is possible to make a thorough comparison of numerical simulations with the experimental data. Agreement between measurements and simulations builds confidence in subsequent theoretical calculations.

The event Priscilla was simulated using the FAST2D code.[2] The important physical processes such as thermal layer development and dust entrainment were modeled. Three separate calculations with progressively more of the pertinent physics included were completed. Results of the detailed comparisons between these calculations and the experimental data show good agreement. Best agreement is found by including the thermal layer and the entrained dust. These two effects work in opposite directions. That is, the thermal layer is a heated region where the local sound speed is enhanced, but the dust adds mass which tends to cool the local volume. The former produces a strong precursor while the latter tends to weaken the effect. By choice of the appropriate models good agreement between calculation and experiment has been achieved.

Manuscript approved February 19, 1985.

II. CALCULATIONAL PROCEDURE

Shot Priscilla was a 37-kton nuclear explosion detonated 700 feet above the ground surface. This configuration was modeled with cylindrical (r-z) geometry. Constant grid separation with $\Delta r = 1$ meter and $\Delta z = 1$ meter were chosen. Initialization of the blast flow field was taken from the 1 KT nuclear standard[3]. The initialization took place 61 ms after disassembly, which is appropriate for a blast wave at a radius of 690 feet.

Figure 1, which is a contour plot of density, indicates this configuration. The model for the thermal layer was taken from Kuhl.[4] Figure 2 shows the effective sound speed versus distance for the Priscilla event. The sound speeds are computed from the shock time of arrival using the Rankine-Hugoniot jump conditions. It is interesting to note that computationally this curve provides a straightforward way to include the hot layer near the ground. However, it represents a combination of all the effects in the thermal layer. As the shock proceeds along the ground surface, it encounters the previously heated ground, convectively mixed air, and elevated and entrained dust particles. For our calculations the thermal layer is assumed to be clean and in pressure equilibrium. This layer was implemented in the code by defining the bottom 3 zones to have a density inferred from the temperature model and consistent with pressure equilibrium.

The dust is treated as separate fluid and becomes entrained at a rate proportional to the horizontal velocity in the first zone adjoining the ground surface:

$$\frac{d\rho}{dt} = 0.08 \frac{\rho V}{\Delta Z} r .$$

It is assumed that the elevated particles are at the same temperature as the local fluid, so that the dust entrainment process adds energy as well as mass (but not momentum) to the flow. The process of entrainment continues

as long as the horizontal velocity at ground level remains nonzero. By the end of the calculation described here, approximately two kton of dust is in the flow field, and the amount has almost saturated. There is no mechanism for dust fallout.

III. CALCULATIONAL RESULTS

The evolution of the shock structure and its interaction with the heated layer and dust are presented in a series of contour plots at different selected times. The first five figures (Figures 3-7) show density contours in the ideal case (Priscilla without thermal layer). Distances in the figures are given in centimeters. A window of 277 meters in the radial direction is shown. Figure 4 shows the Mach stem, reflected shock, slip surface, and the incident shock. At 0.686 sec., Fig. 7, the triple point has risen to a height of 114 meters.

Figures 8-17 show the case with a heated layer but no dust. The figures show density and pressure contours at each display time. In Fig. 8 one can see the beginning of the precursor as the shock runs out ahead of what would have been the Mach stem. Figure 10 at 0.298 seconds shows the considerable detail of the very complex flow. A pronounced contact discontinuity is present in the lower right hand edge of this figure (note its presence in density but not pressure). This represents the interface between the thermal layer and the ambient air after the passage of the precursor shock. Comparison of Fig. 10 and 11 show numerous triple points which are terminations of the shocks produced by the reflections and rarefactions that occur as the spherical incident shock encounters the hot thermal layer. Figures 12 and 13 reveal a large rollup behind what would normally be the Mach stem. Moving forward from this rollup is a higher-density cold jet of air. Further evolution of the structure is seen in Figs. 14 and 15, and finally in Figs.

16 and 17 the first triple point is at 136 meters.

The final calculation includes the effects of the dust. Figures 18-29 show total density, dust density and pressure at different times. Figures 18-20 correspond to the clean flow case, Fig. 8 and 9, and to the ideal case, Fig. 4. Morever, the times are comparable for each set of figures, enabling a direct comparison of the three cases. The primary difference between this last case and the previous two results from the presence of the dust. The dust density contours reveal a considerable lip of dust emerging as the large vortex develops behind the Mach stem position. In addition, the extra shocks that were present in the clean flow (cf., eg., Fig. 16 and Fig. 29) have disappeared. Both the outrunning precursed shock and the shock linking the reflected shock to the upper Mach stem are missing. There are four triple points present as one moves down along the incident shock. The first triple point is located at 108 meters height. In Fig. 29 only two triple points are observable, the first being at 94 meters.

IV. PRISCILLA EXPERIMENTAL DATA AND COMPARISONS

The data from the Priscilla test is contained in several reports. Reference 1 describes the basic airblast phenomena while additional data from the Stanford Research Institute (SRI) measurements is found in Ref. 5. The data has been assembled and is presented here in three formats. First, the time of arrival (TOA) of the first wave (precursor) is given as a function of ground range. The agreement between data and calculation is an indication that the choice of thermal layer and dust model is reasonable. This should be regarded only as a crude test since TOA is one of the easiest curves to match in airblast simulations. Second, the peak overpressure versus distance data is presented. This has long been regarded as a good test of agreement between test data and calculations. Additionally, the dynamic

pressure ($0.5\rho v^2$) is plotted against range as an adjunct to the overpressure data. The values of dynamic pressure at larger ranges are uncorrected.

Figure 30a contains the TOA experimental data. The symbols denote separate experiments that were fielded on Priscilla. Large scatter exists in most of the data except for the SRI experiment. Figure 31a displays the peak-overpressure-versus-range data, and Fig. 32a shows the few values of dynamic pressure obtained. For each of the above figures the values from the calculations are plotted on a transparent overlay. Direct comparisons can thus be made by using Figs. 30a and 30b, Figs. 31a and 31b, and Fig. 32a and 32b.

A more stringent comparison can be made by actually comparing the experimental station data. At a fixed location values of overpressure and dynamic pressure were recorded as functions of time. The SRI data is deemed to be more reliable and better resolved[6] and will be used for the comparison.

In order to condense the information each plot displays four curves. Curve A is the ideal calculation, curve B is the clean flow, curve C is the dusty-flow calculation and curve D is, of course, the experimental data.

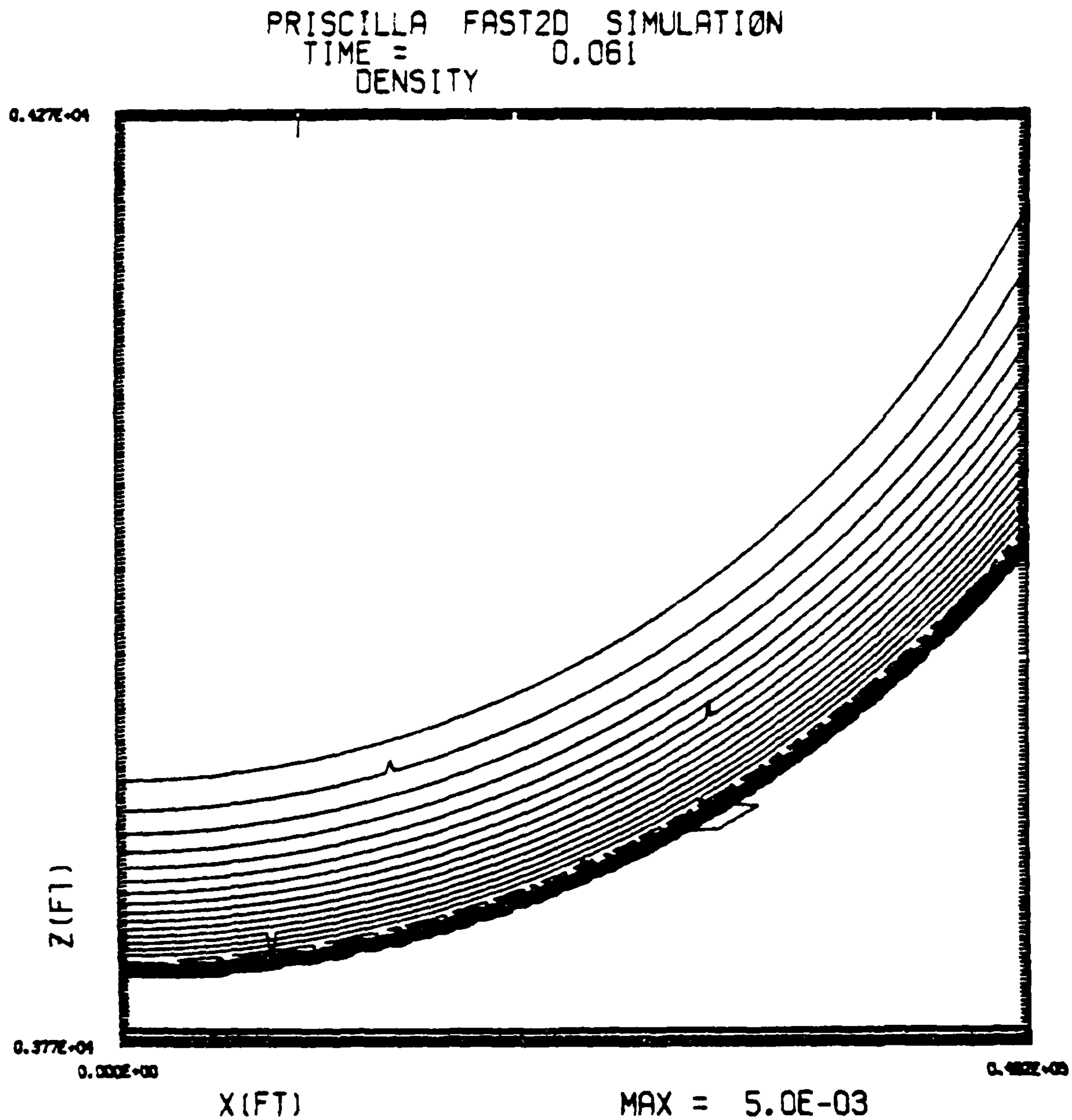
The comparison first begins with Fig. 33, which displays overpressure versus time for the 450-ft station. All three calculations A, B, and C have approximately the same shape and TOA, 0.106 sec. Figure 34 shows the overpressure at the 550-ft station. Definite structure begins to appear in B (clean) and C (dusty) while A (ideal) begins to lag in arrival time. The data (D) at this station indicates a faster-moving signal arriving at 0.117 sec. In Fig. 35 the first indication of precursed wave is seen in the calculations. The 650-ft station is approaching the point of transition to double Mach configuration in the ideal case A. Lack of resolution in the computational grid probably accounts for the disagreement in the arrival

times up to this point. The precursor must develop a physical dimension equivalent to several meters (several zone widths) before it is represented in the three-point algorithm. Also the reduced peaks (in relation to B) are attributable to the coarse resolution.

Figures 36 and 37 show better agreement between arrival times. Note curves B and C compared to D. Figures 38 and 39 are at ground ranges of 1050 and 1350 feet, respectively. Negative overpressures begin to appear in B after the arrival of the precursor and before the main compression wave. Figures 40-42 show the 1650-ft station at 0, 3, and 10 feet, respectively. Curves C are somewhat better in comparison to D.

Figures 41-49 detail the dynamic pressure versus time for the same station locations as the static overpressure. Examination of Fig. 49 shows much better agreement with C and D; curve B differs by an order of magnitude. The general trend shows better agreement when both dust and thermal layer are included. Since the effects compete against each other, one need only vary the important parameters in the models to achieve better agreement. The temperature would be adjusted downward to retard the time of arrival, while decreased dust should increase the dynamic pressure.

In conclusion, the event Priscilla has been simulated with a series of calculations. The results of the calculations when compared to the actual experimental data indicate the importance of the hot thermal layer in the flow field. Moreover, the addition of dust to the flow is mandatory in order to achieve reasonable agreement with the dynamic pressure. This comparison shows that non-ideal effects in airblast can be computed with reasonable agreement with experimental data.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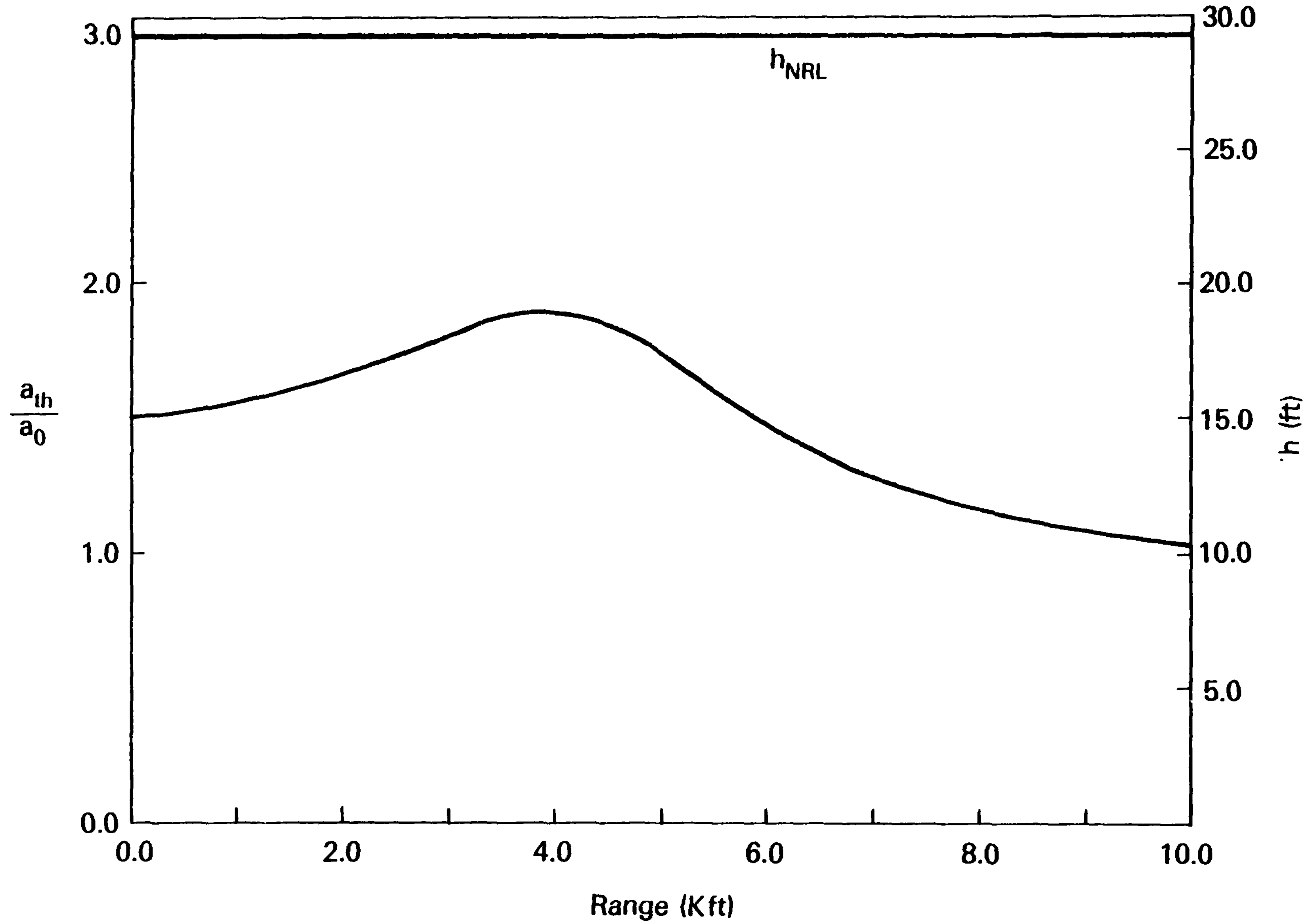
Z(FT)
X(FT)
MAX = 5.0E-03

Figure 1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1.0
0.0
$\frac{a_{th}}{a_0}$
30.0
25.0
20.0
15.0
10.0
5.0
h (ft)
h_{NRL}
0.0
2.0
4.0
6.0
8.0
10.0
Range (Kft)

Figure 2

PRISCILLA WITHOUT THERMAL LAYER

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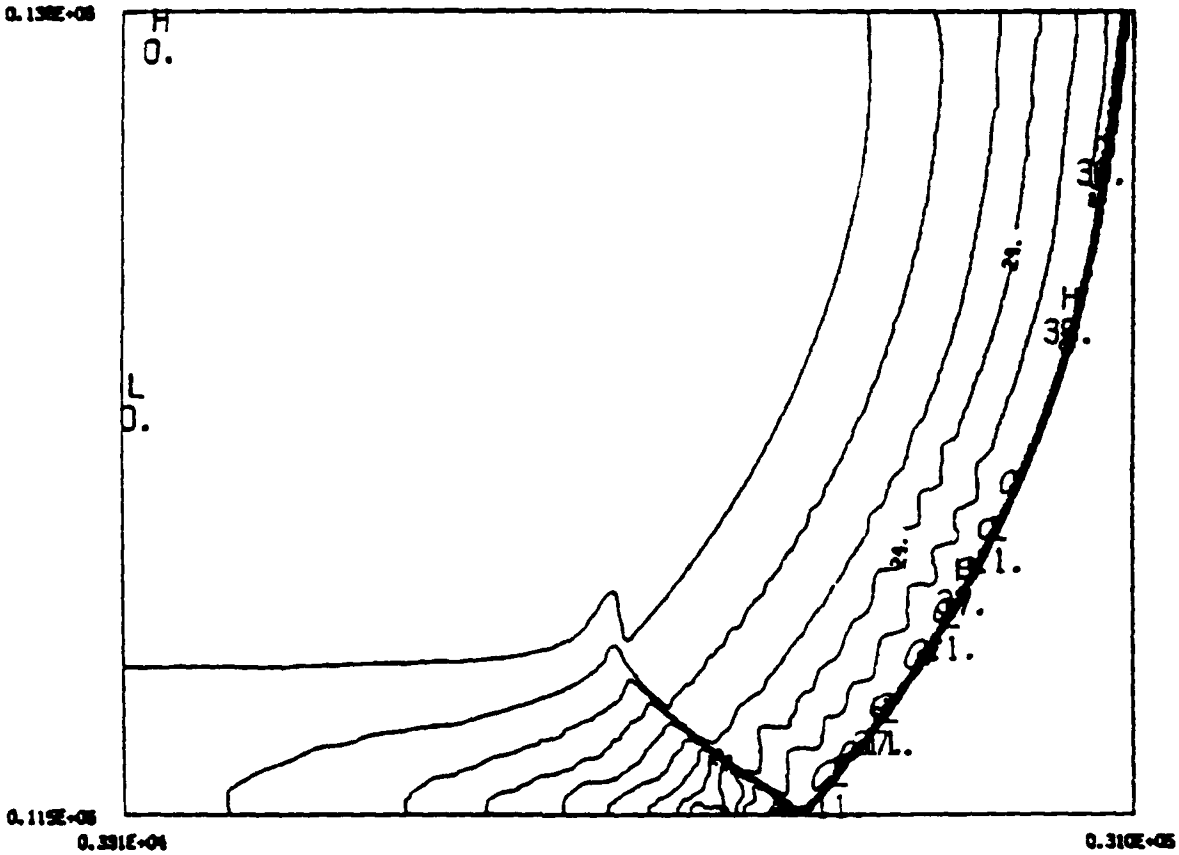

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Figure 3

PRISCILLA WITHOUT THERMAL LAYER

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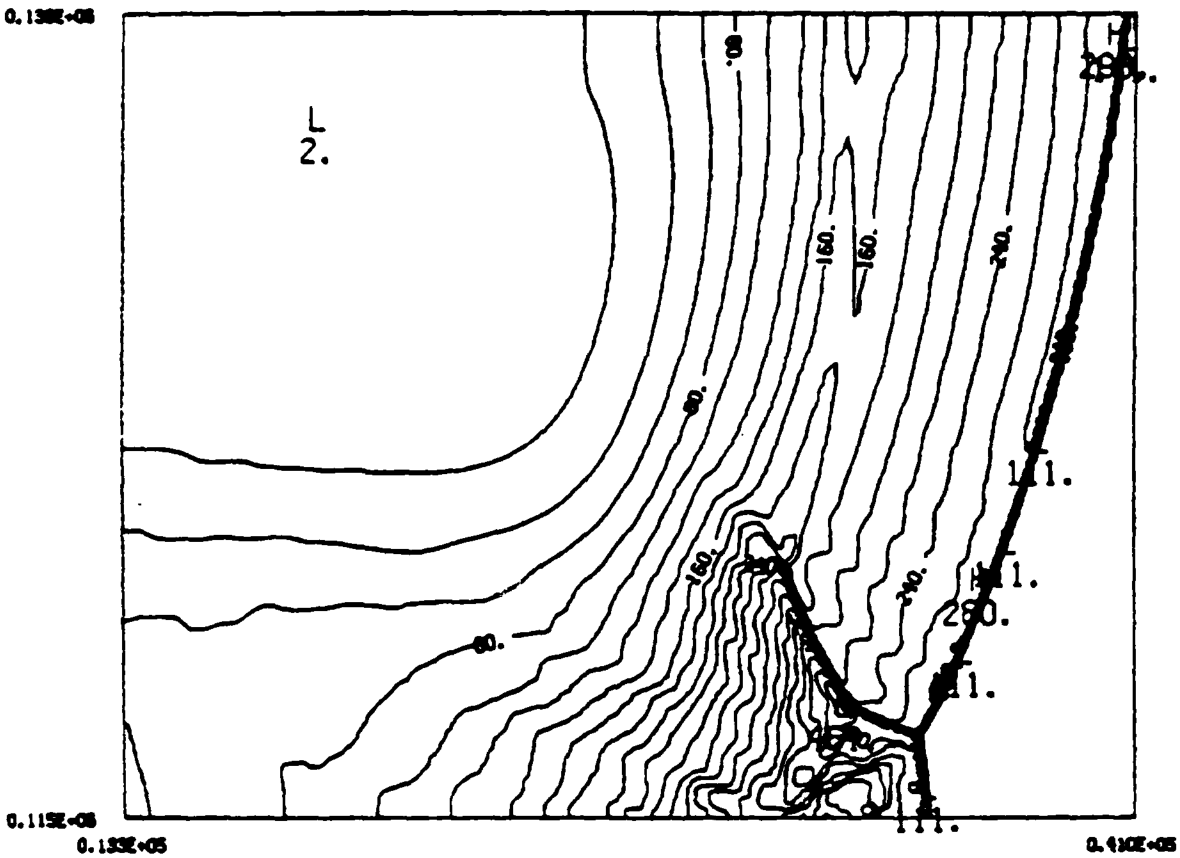
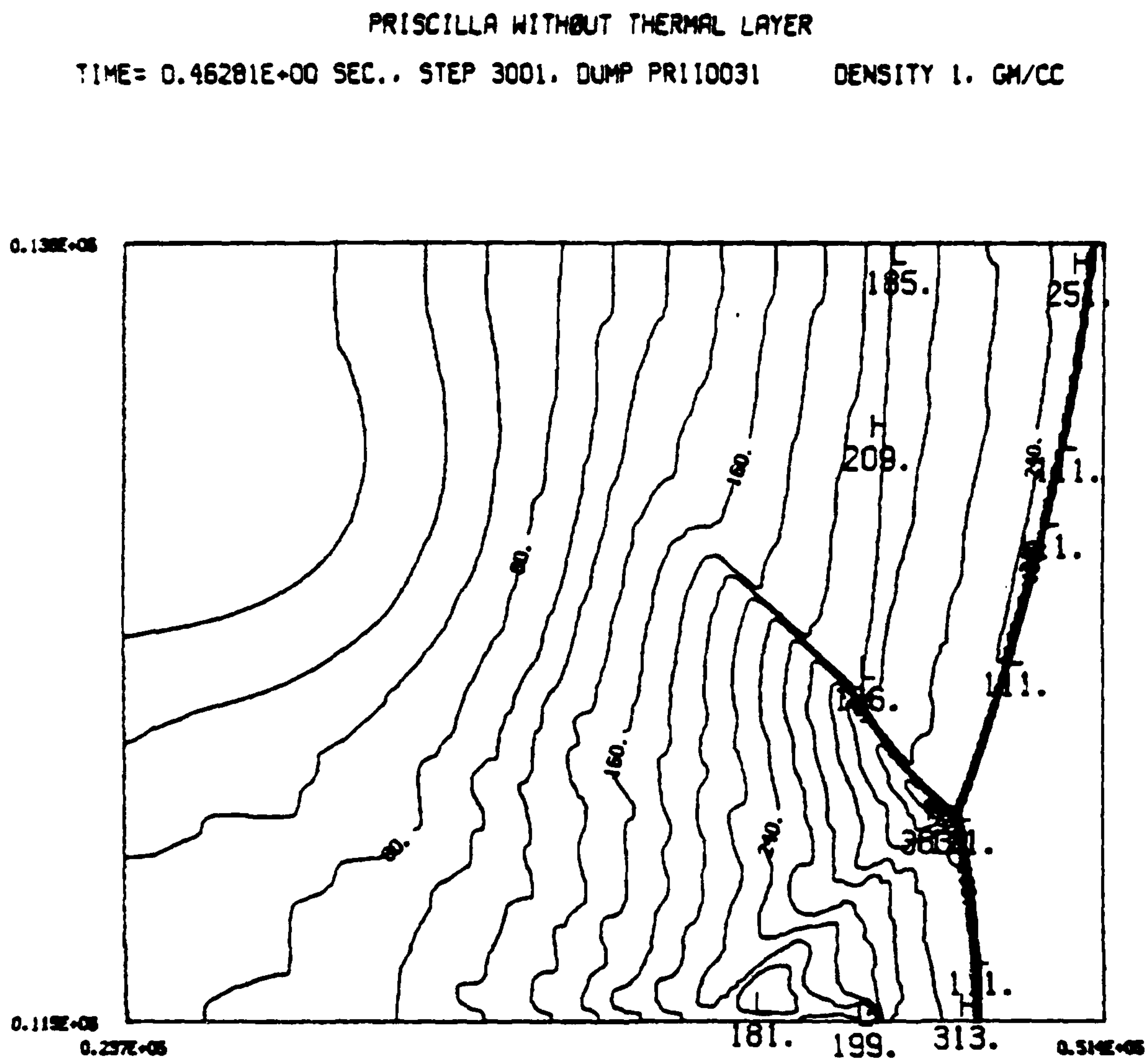


Figure 4


PRISCILLA WITHØUT THERMAL LAYER
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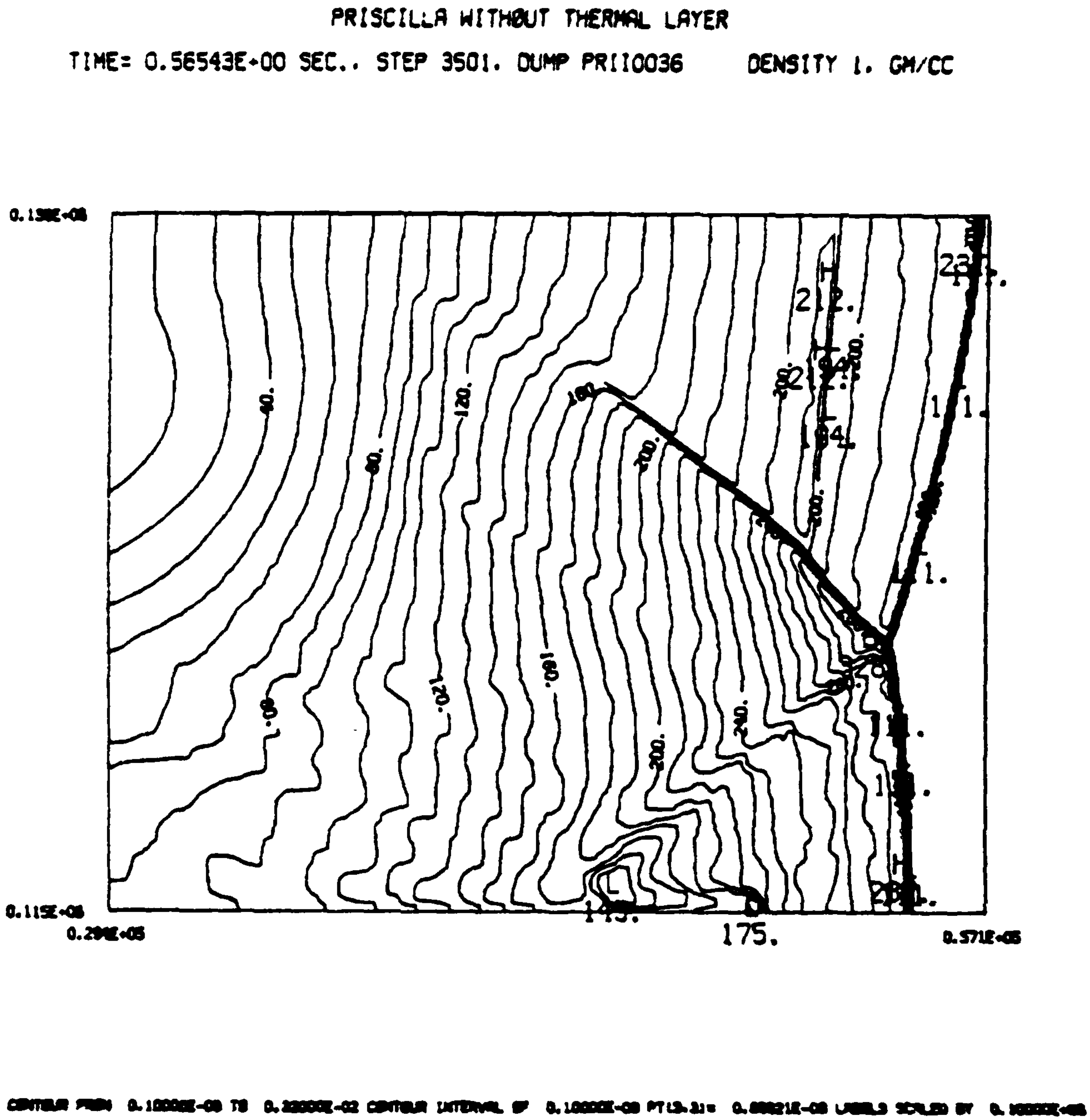
209.
160.
80.
240.
181.
199.
313.

Figure 5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0.115E+06
0.571E+05
40.
80.
120.
160.
200.
240.
212.
175.

Figure 6

PRISCILLA WITHØUT THERMAL LAYER

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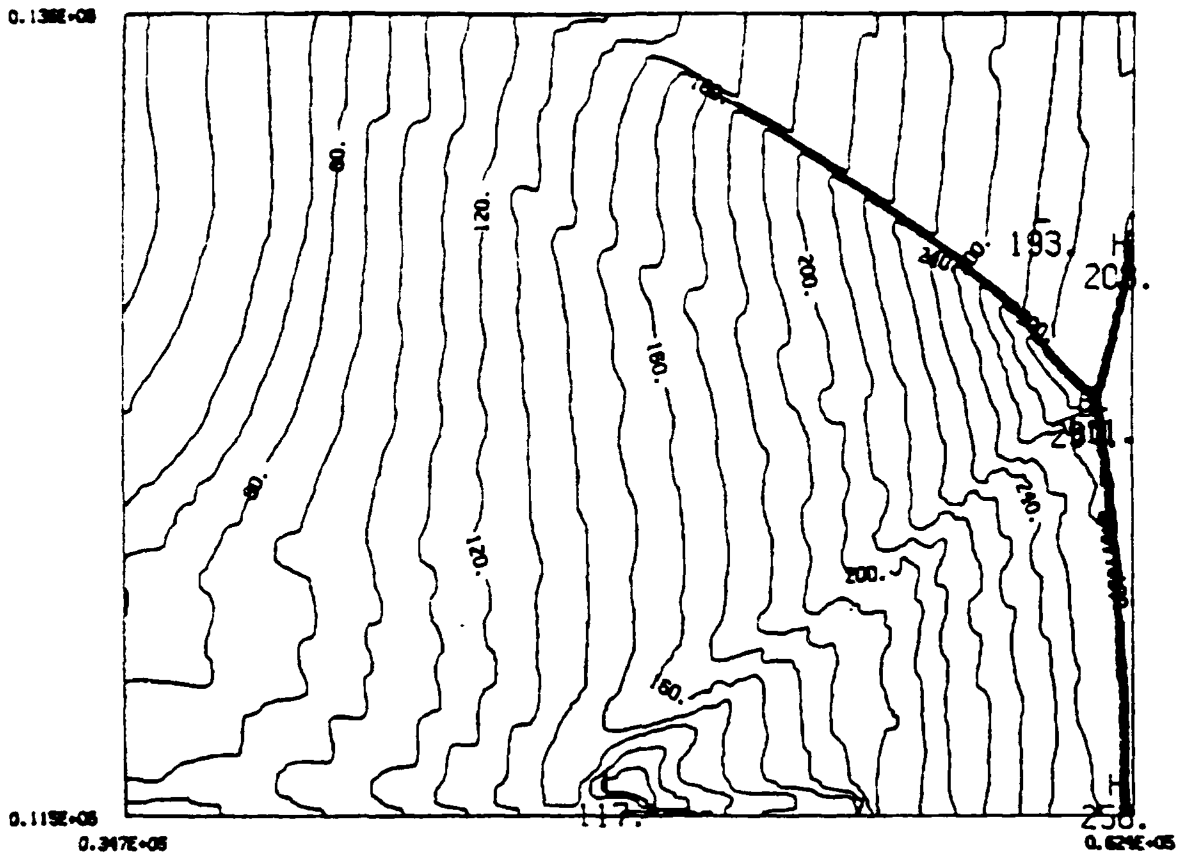

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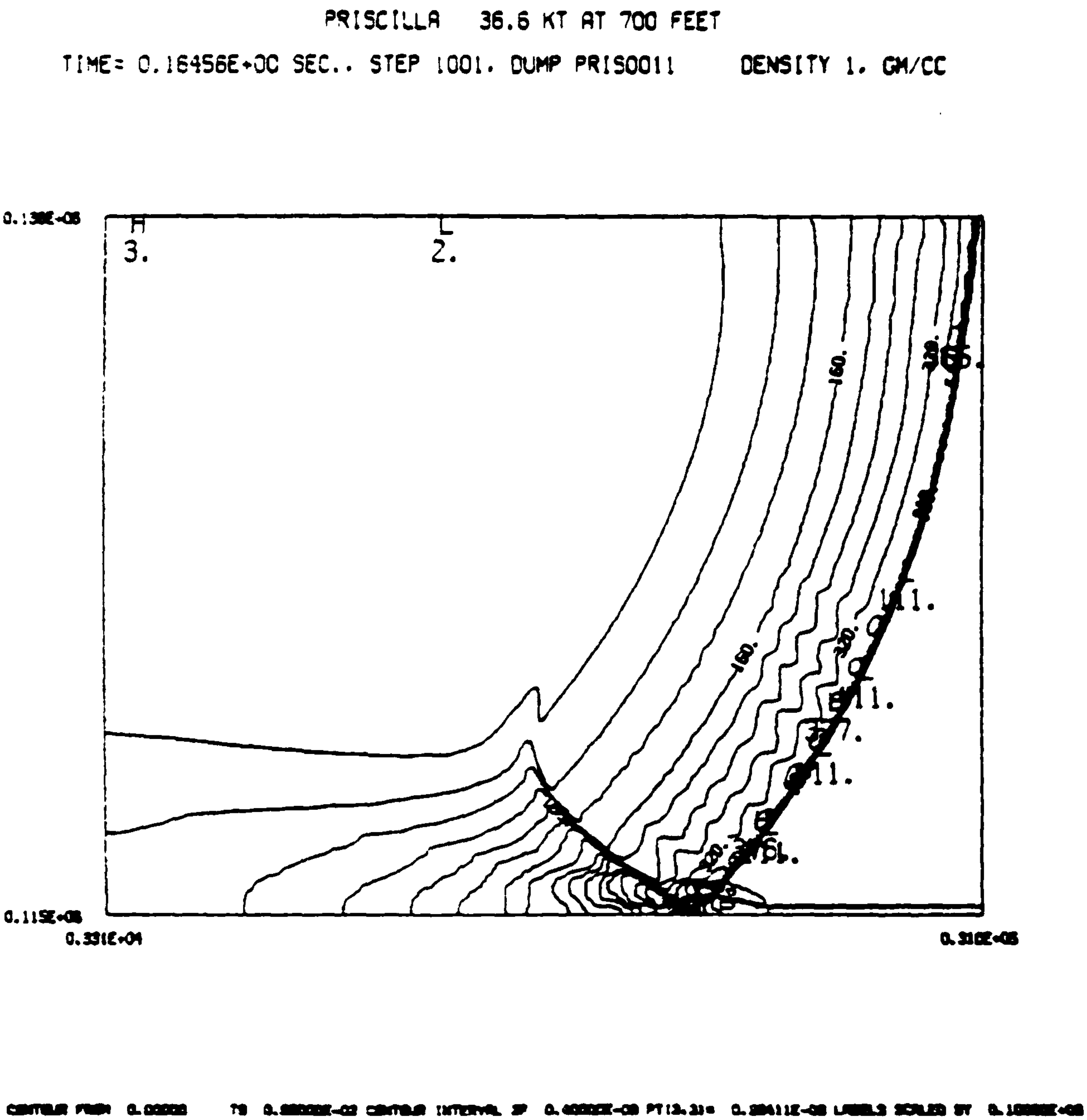
Figure 7


PRISCILLA 36.6 KT AT 700 FEET
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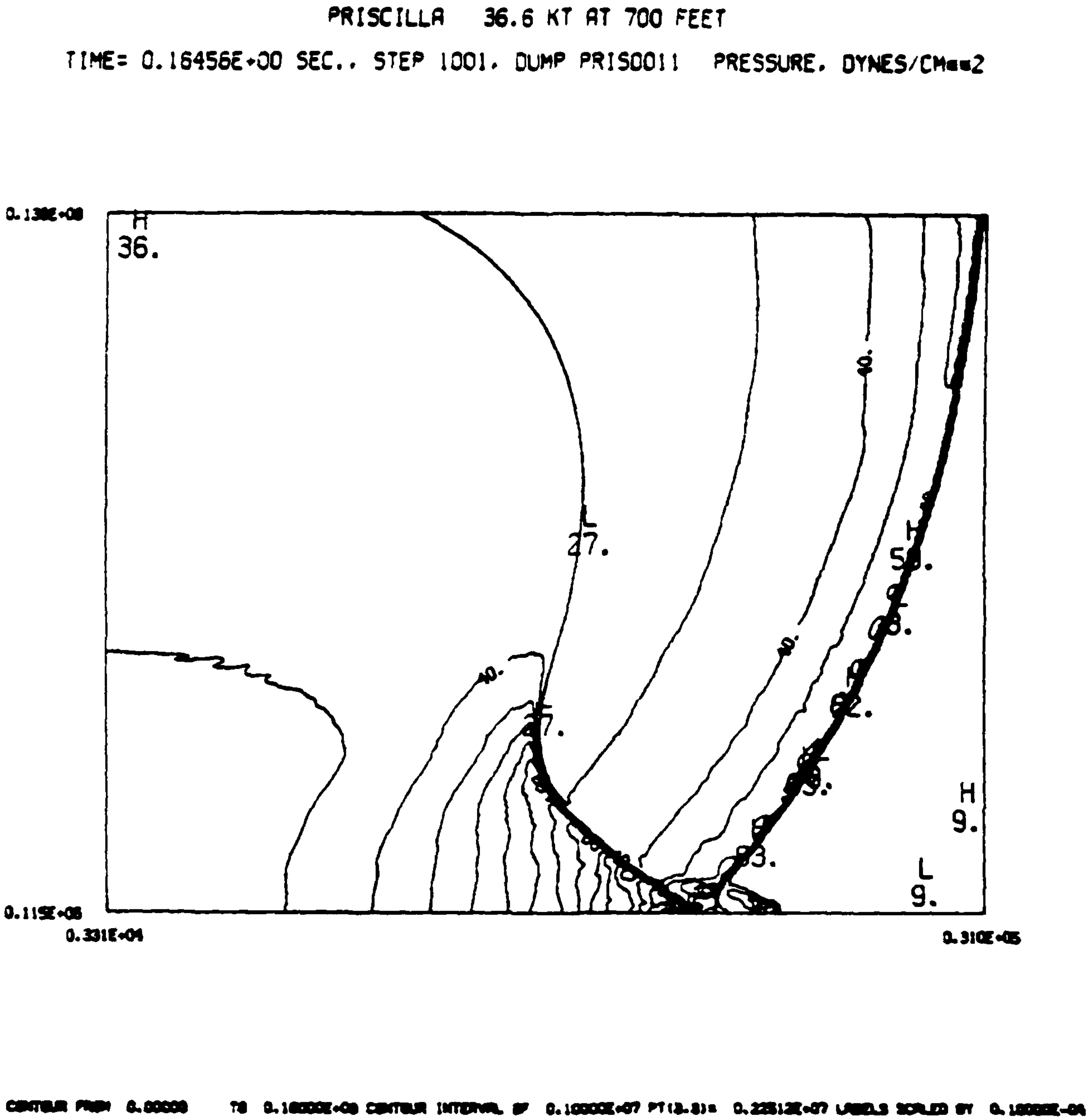
H
3.
L
2.
160.
320.

Figure 8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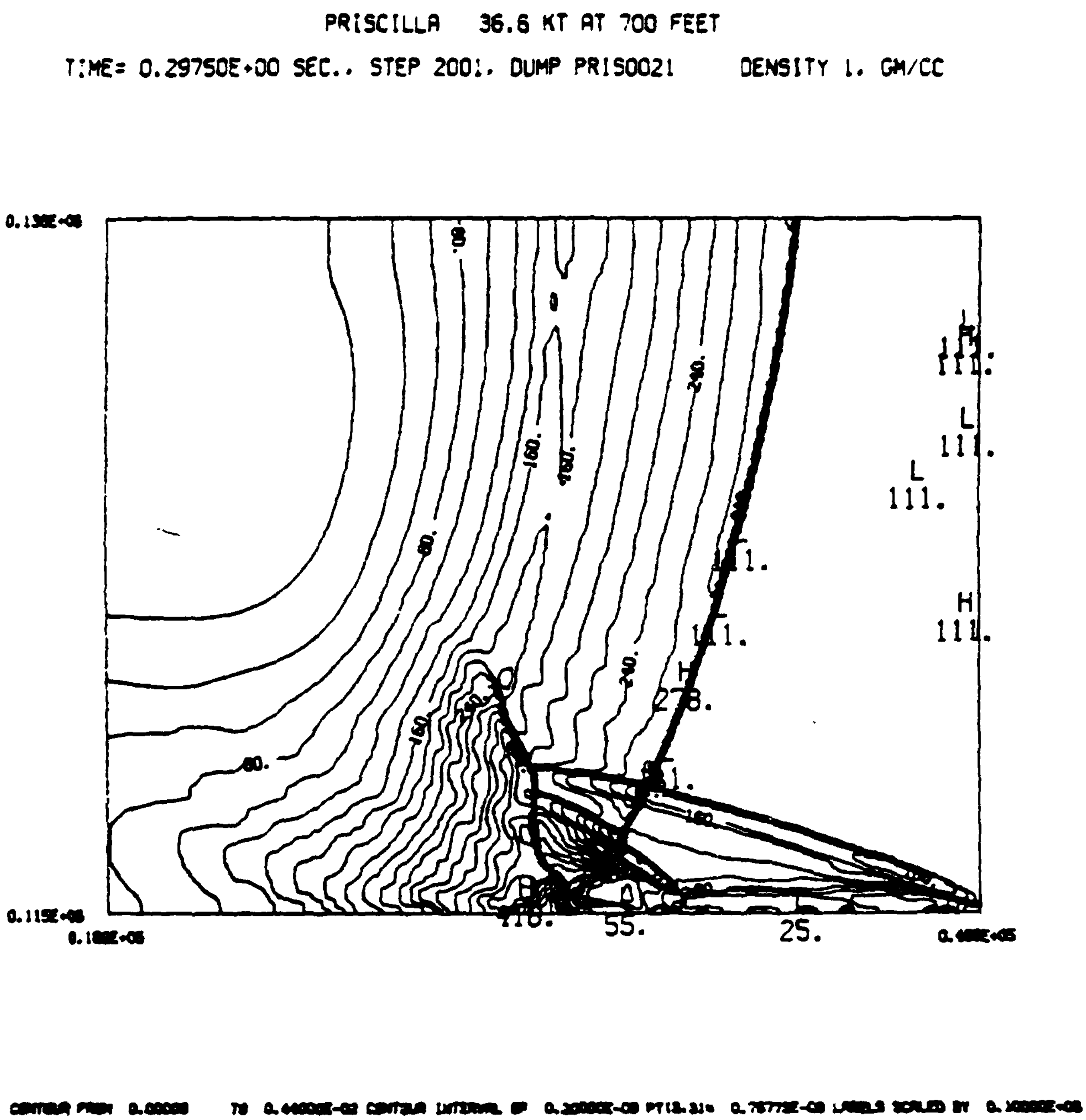
0.115E+08
0.331E+04
0.310E+05
H
36.
L
27.
40.
H
9.
L
9.

Figure 9


PRISCILLA 36.6 KT AT 700 FEET
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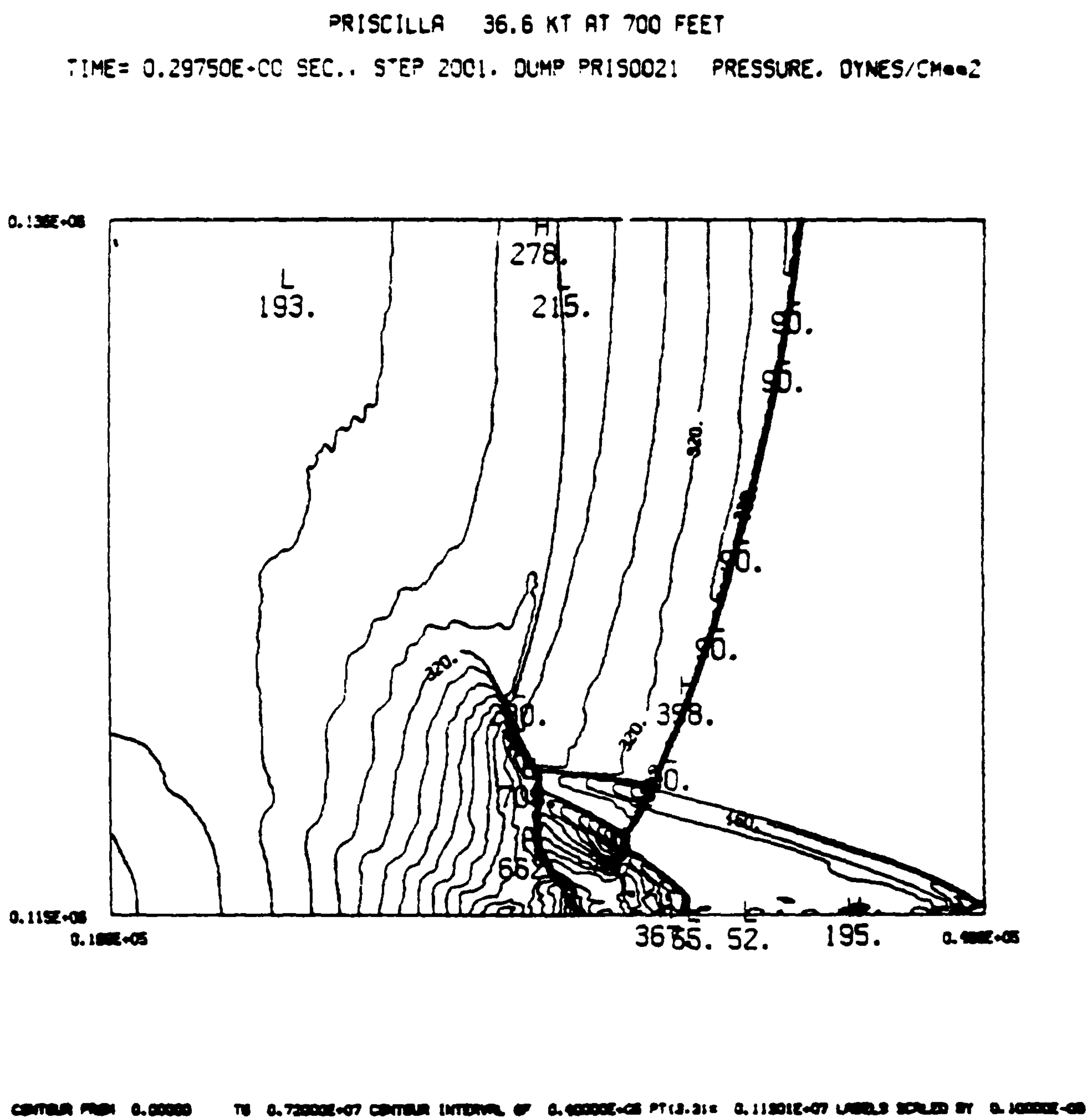
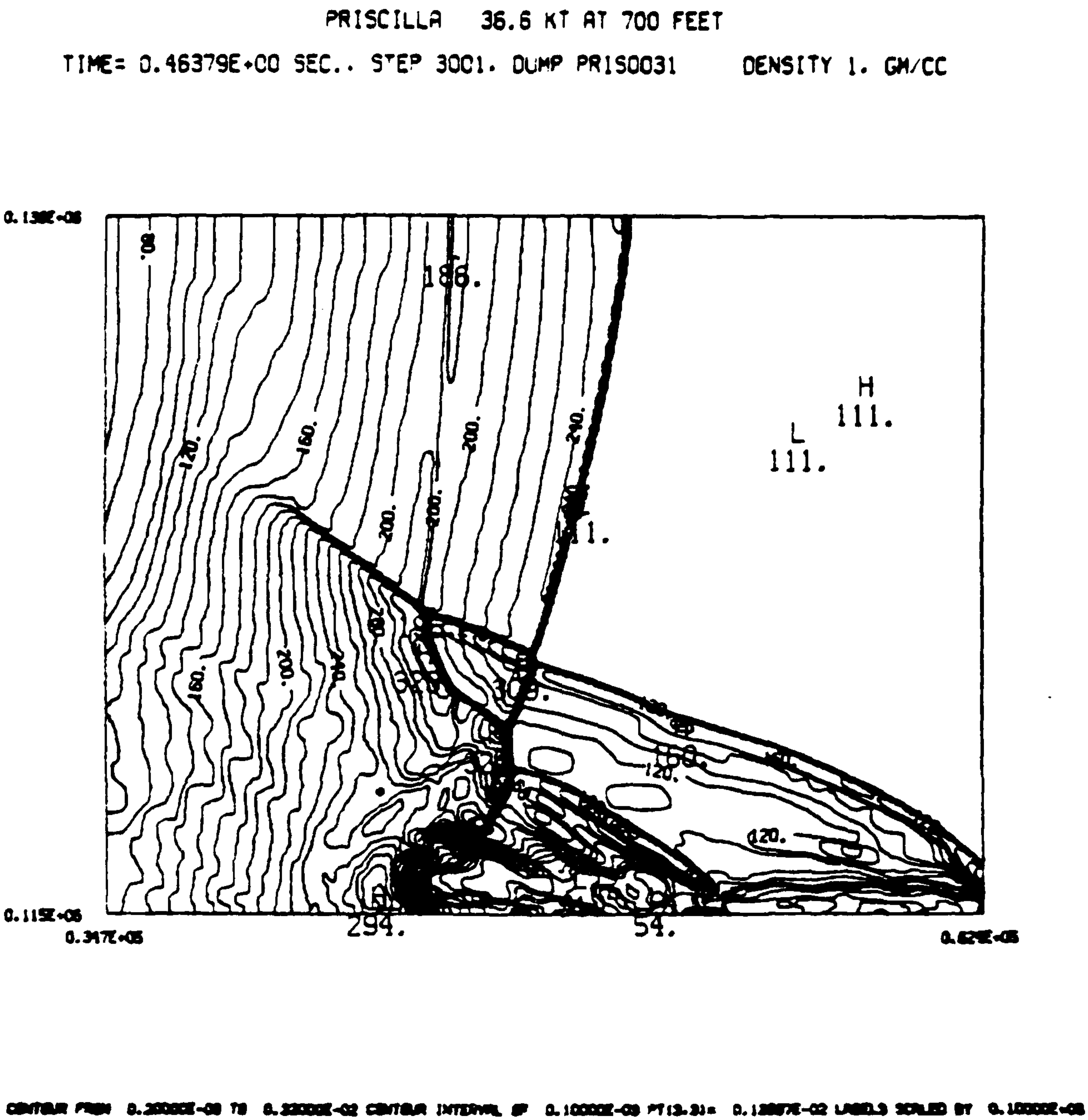
L
111.
H
111.
55.
25.

Figure 10



PRISCILLA 36.6 KT AT 700 FEET
TIME= 0.29750E-CC SEC.. STEP 2001. DUMP PRIS0021 PRESSURE. DYNES/CM**2
L
193.
278.
215.
320.
90.
65.
52.
195.

Figure 11


PRISCILLA 36.6 KT AT 700 FEET
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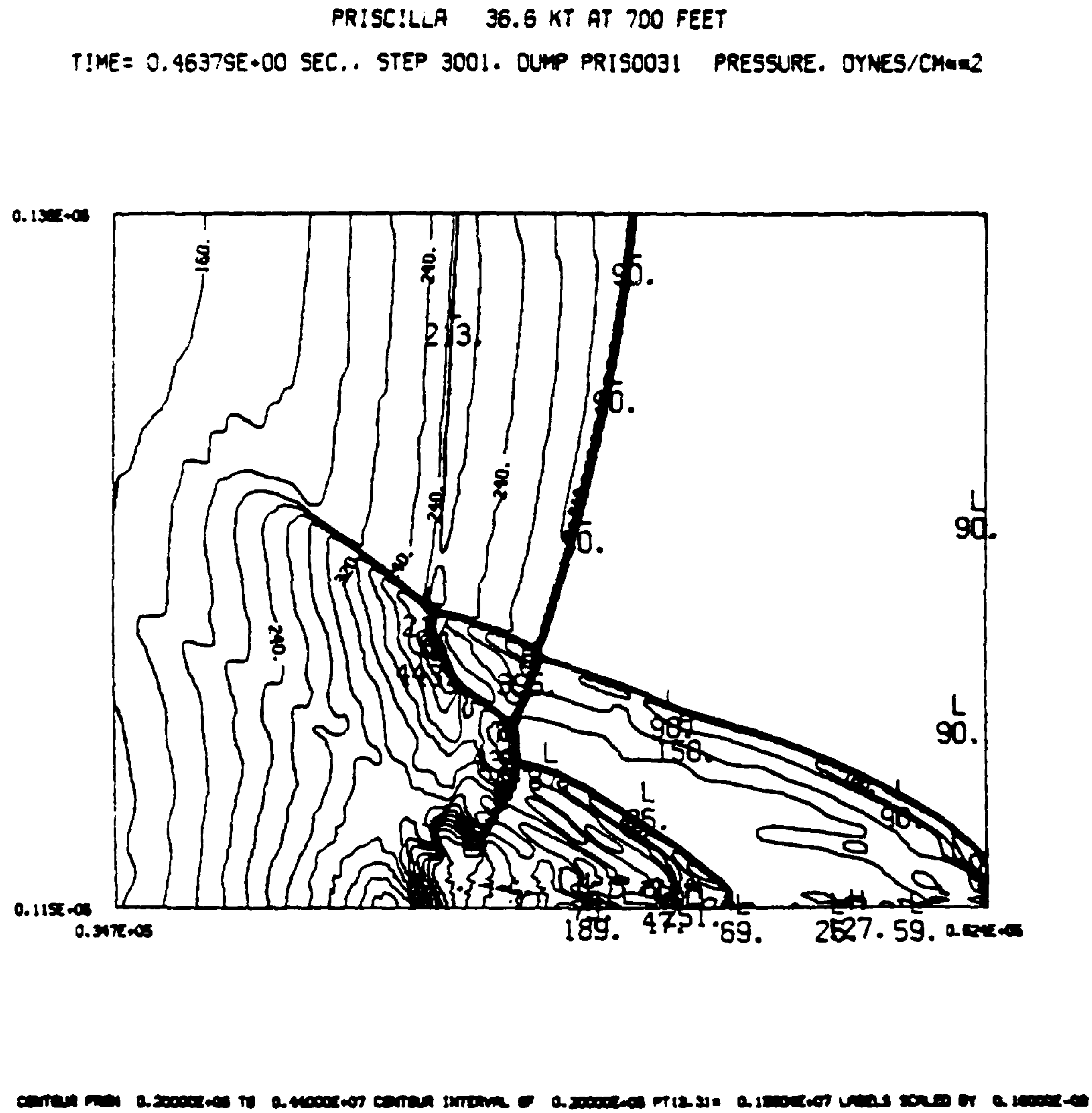
0.115E+05
294.
54.
H
111.
L
111.
186.
120.
160.
200.
240.

Figure 12


PRISCILLA 36.6 KT AT 700 FEET
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0.115E+06
0.347E+05
0.624E+05
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Figure 13

PRISCILLA 36.6 KT AT 700 FEET

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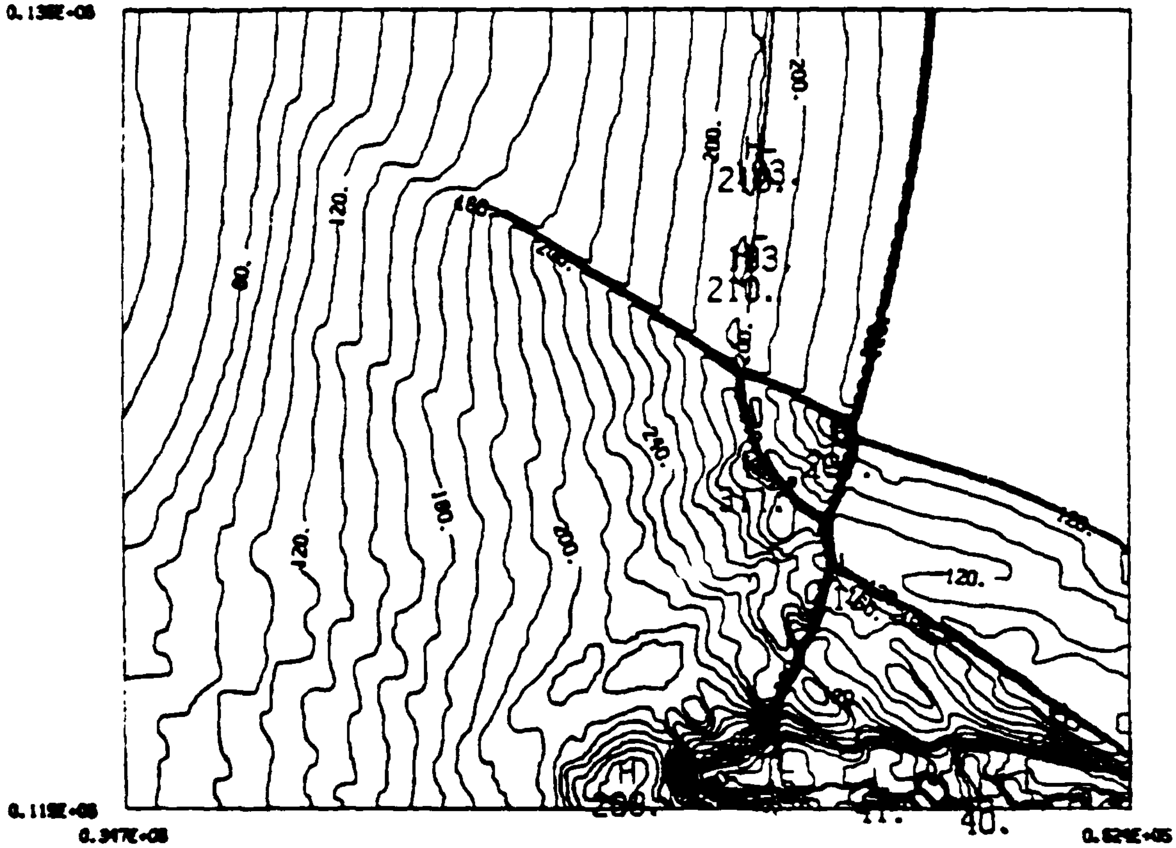

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Figure 14

PRISCILLA 36.6 KT AT 700 FEET

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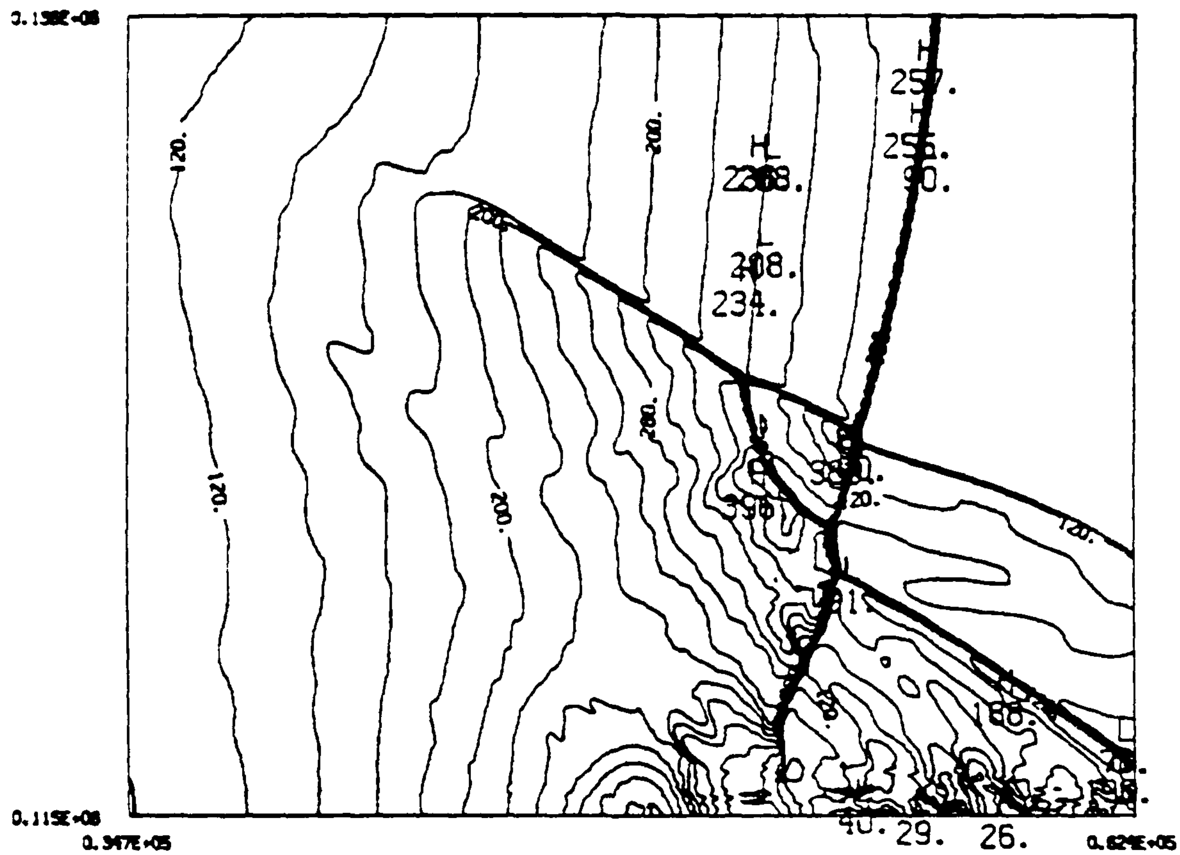

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Figure 15

PRISCILLA   36.6 KT AT 700 FEET

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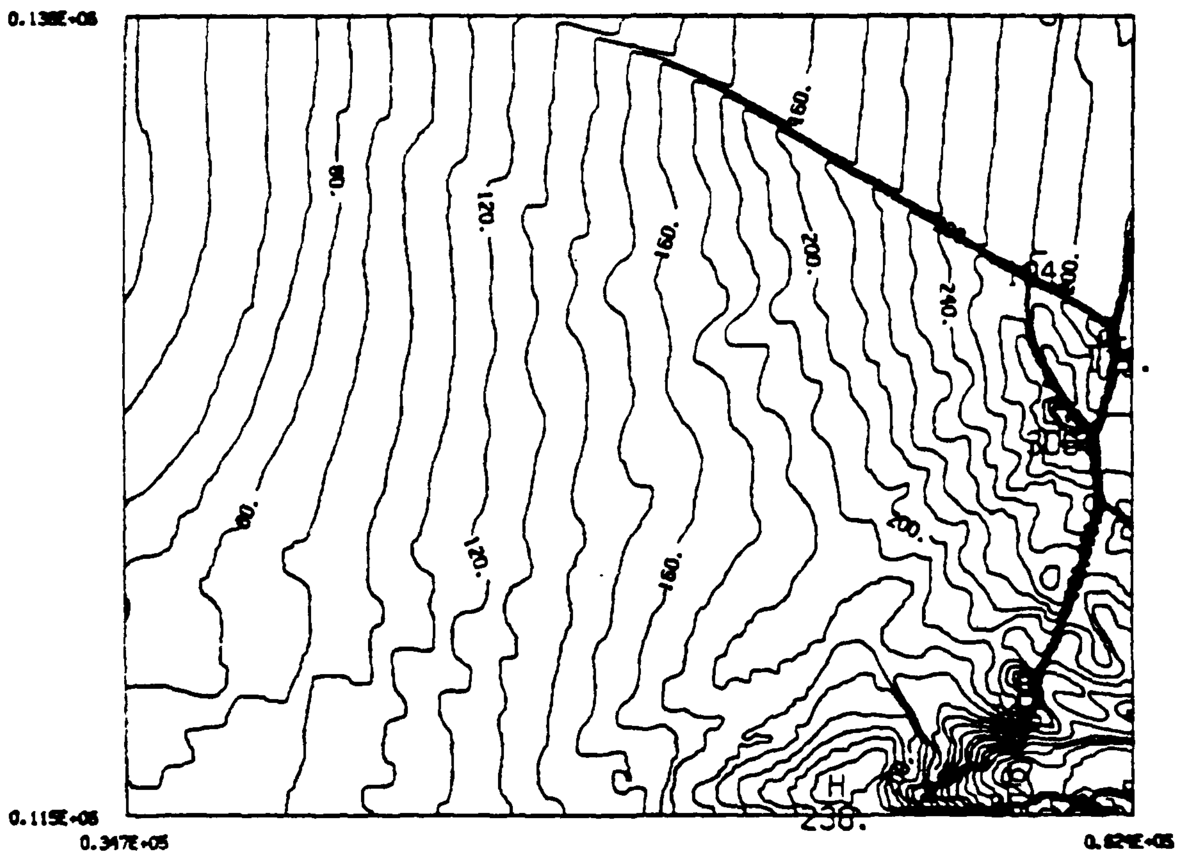

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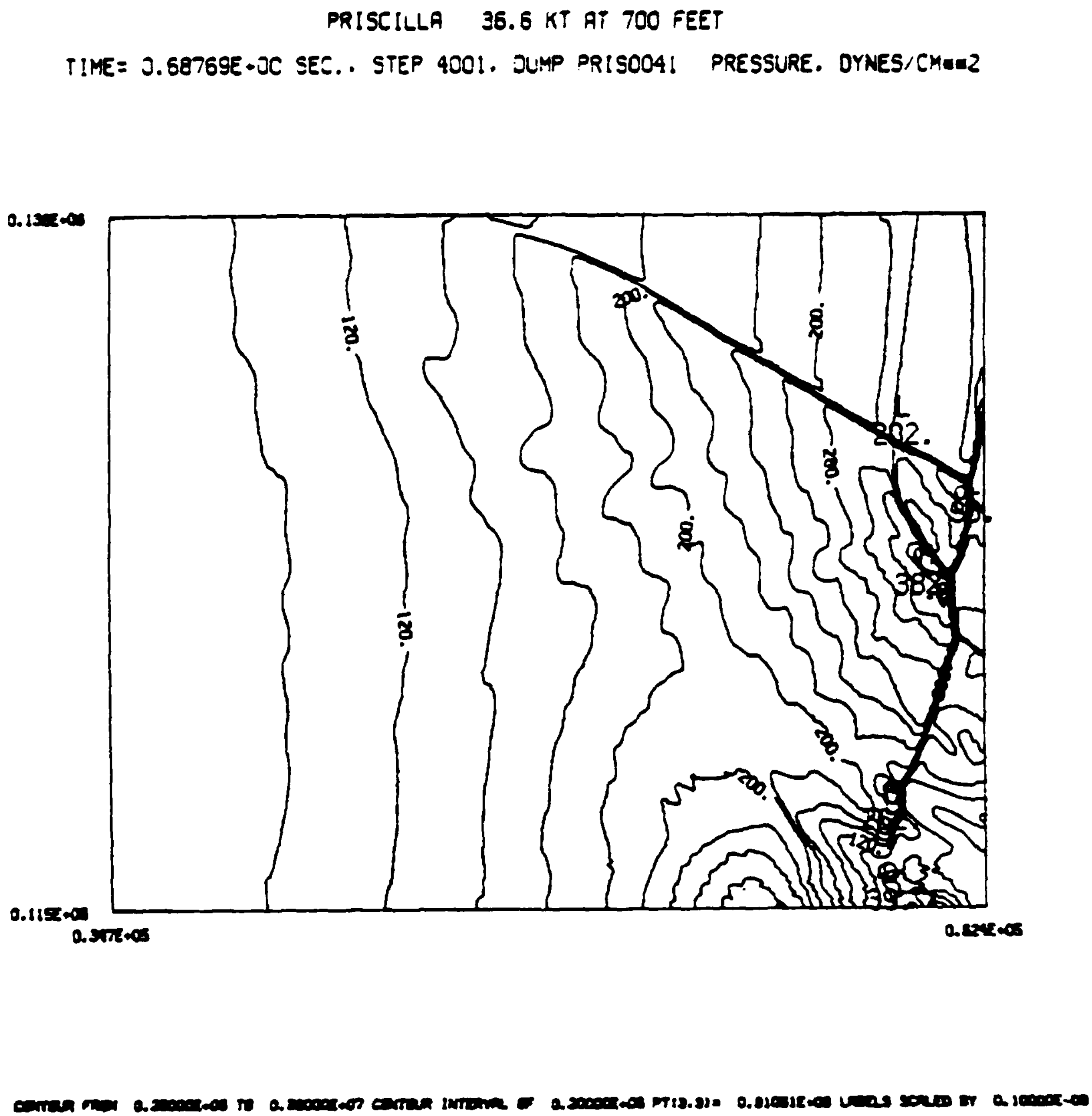
Figure 16



PRISCILLA 36.6 KT AT 700 FEET
TIME= 0.68769E+00 SEC., STEP 4001, DUMP PRIS0041 PRESSURE, DYNES/CM**2
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0.115E+06
0.347E+05
0.824E+05
120.
200.
202.
382.
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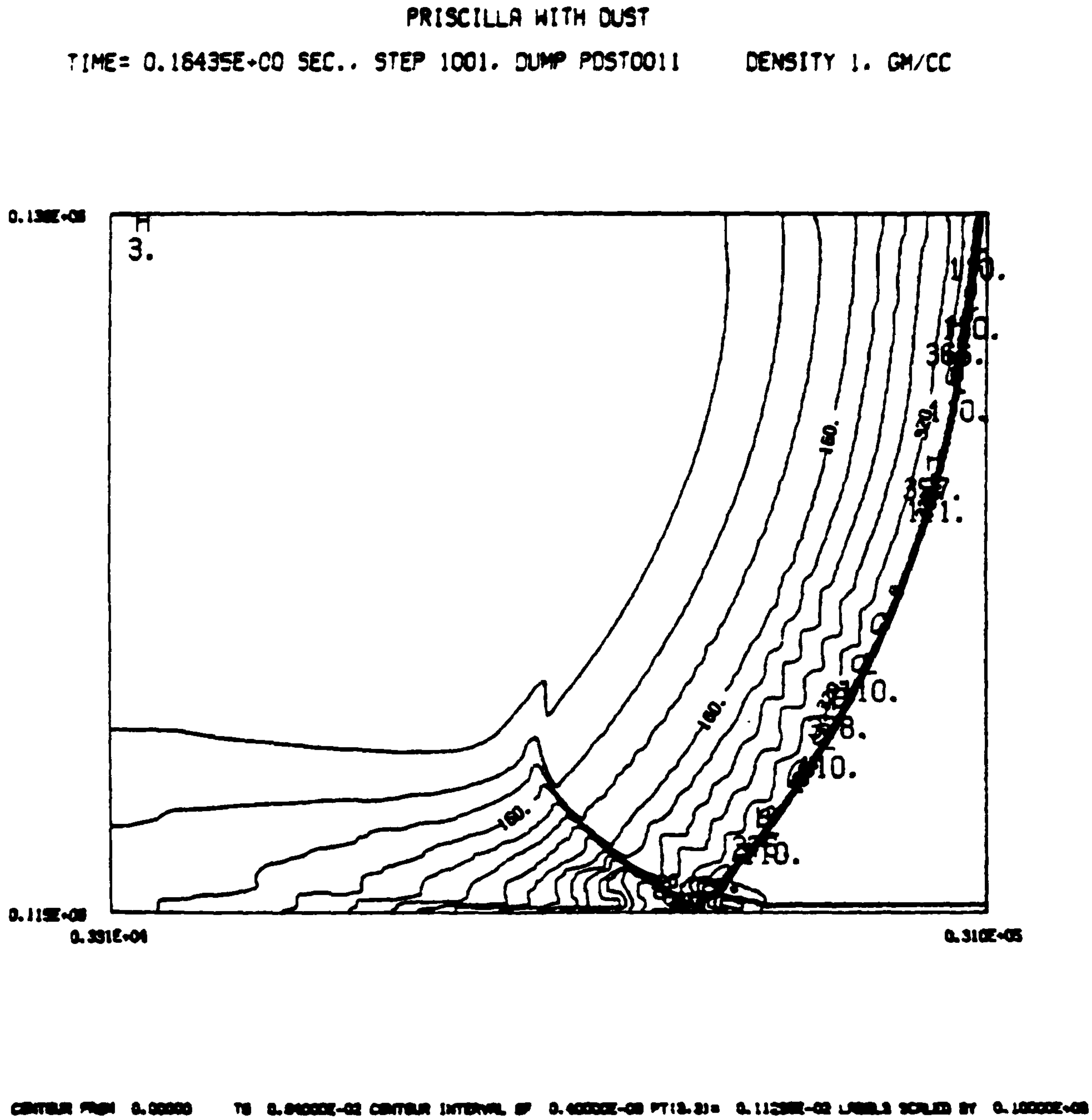
Figure 17


PRISCILLA WITH DUST
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3.
160.

Figure 18

PRISCILLA WITH DUST

TIME= 0.16435E+00 SEC., STEP 1001, DUMP POST0011   DENSITY 2, GM/CC

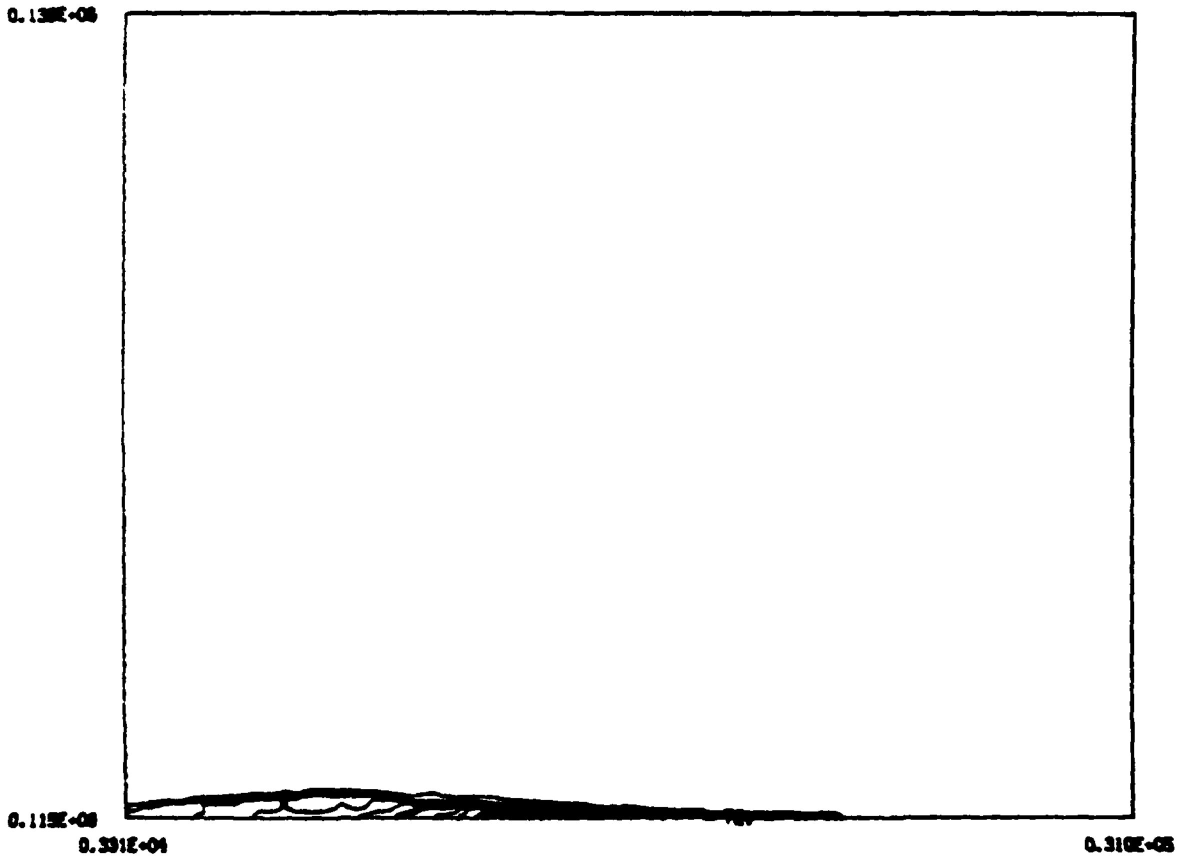

Figure 19

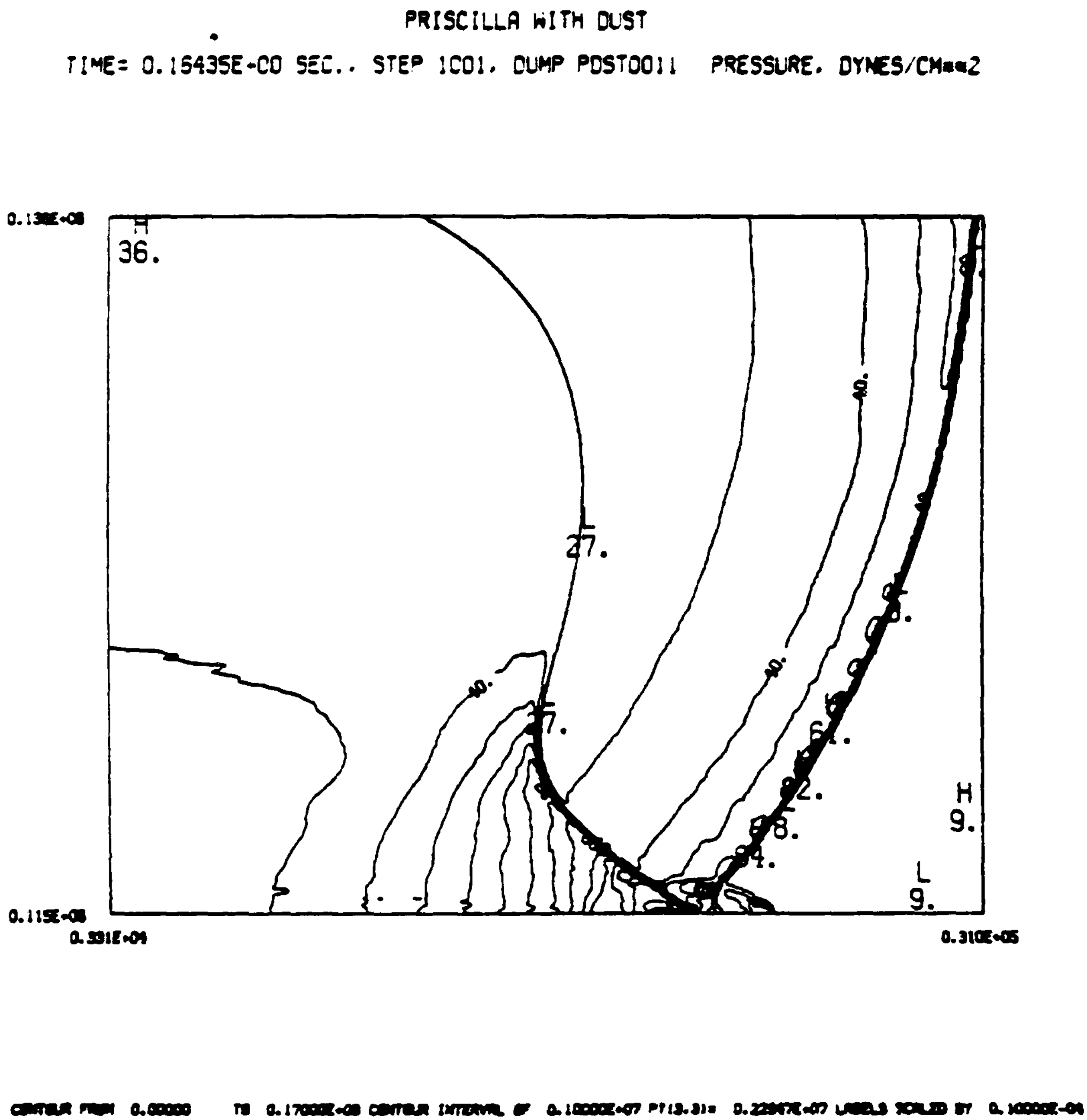
PRISCILLA WITH DUST
TIME= 0.16435E+00 SEC.. STEP 1001. DUMP PDST0011 PRESSURE. DYNES/CM**2
36.
27.
40.
H
9.
L
9.
0.115E+08
0.310E+05

Figure 20

PRISCILLA WITH DUST

TIME= 0.29651E+00 SEC.. STEP 2001. DUMR POST0021 DENSITY 1. GM/CC

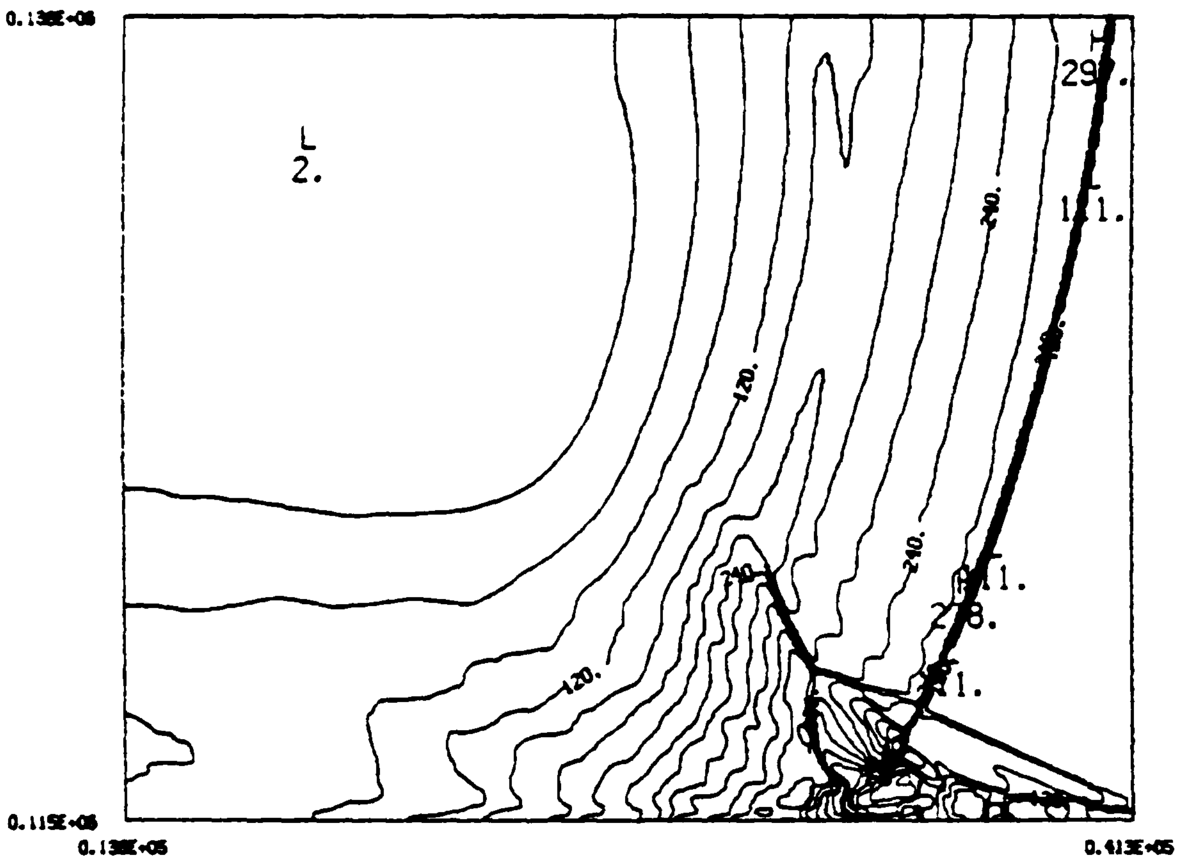

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Figure 21

PRISCILLA WITH DUST

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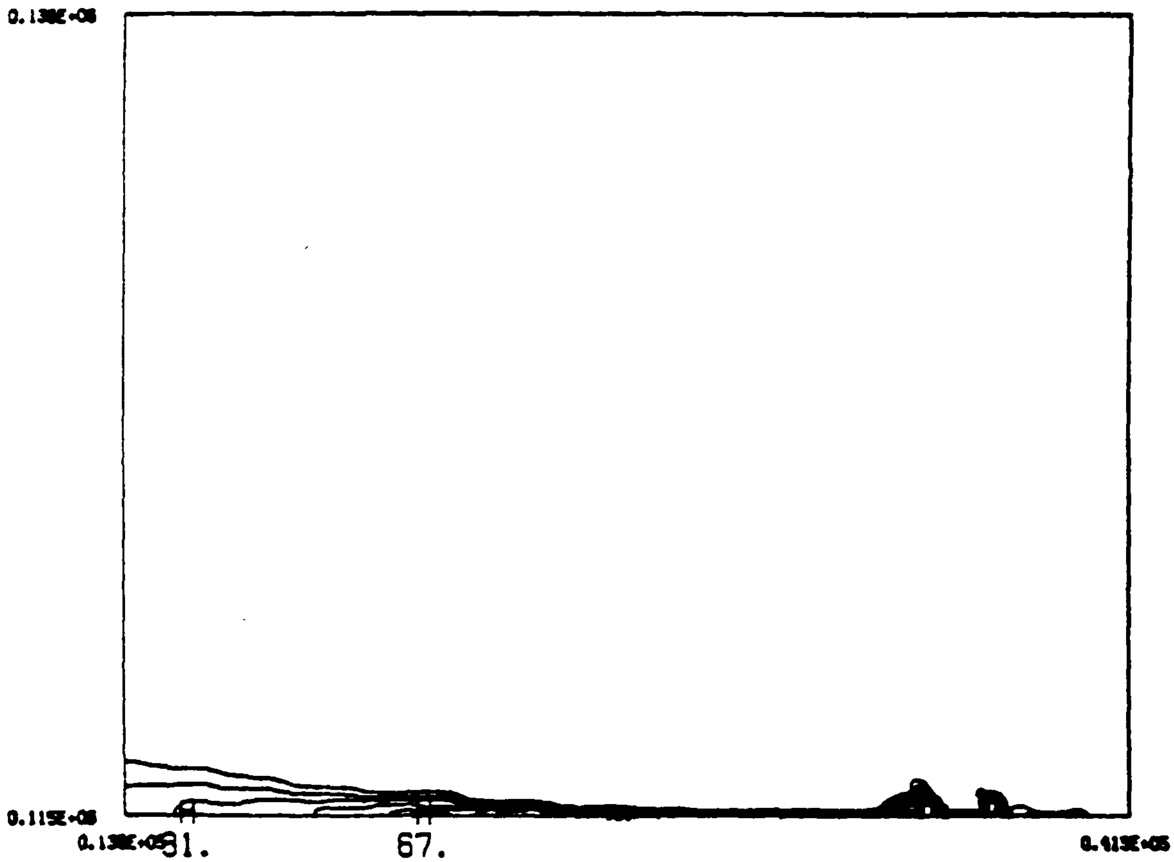

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Figure 22

PRISCILLA WITH DUST

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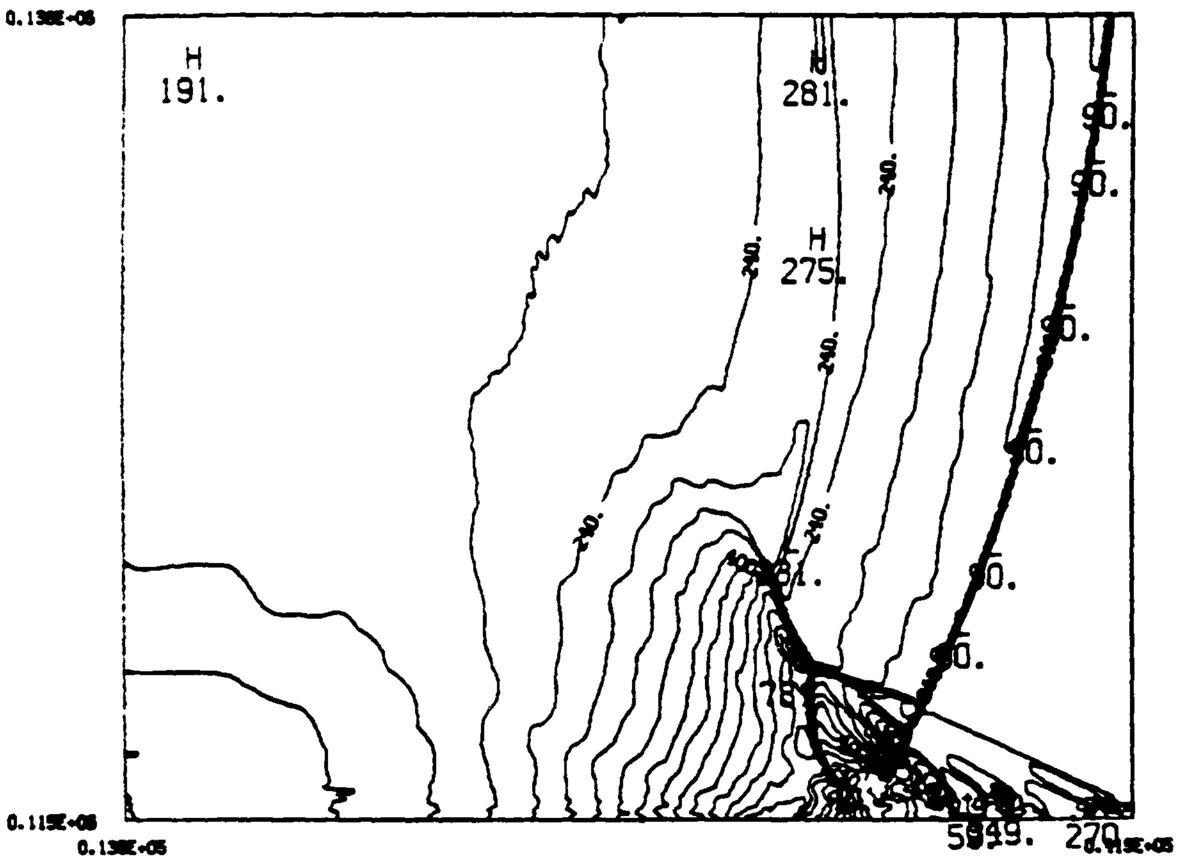

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Figure 23

PRISCILLA WITH DUST

TIME= 0.46293E+00 SEC., STEP 3001, DUMP PDST0031   DENSITY 1. GM/CC

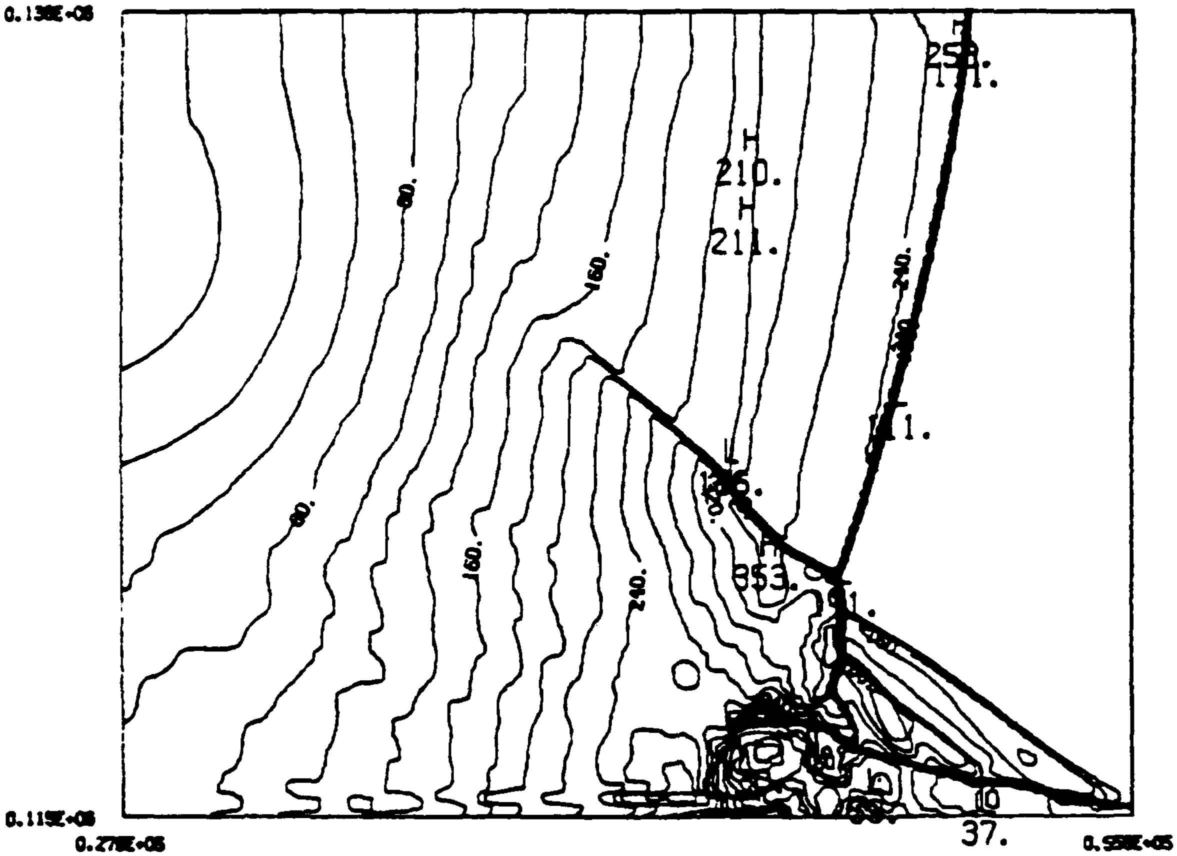
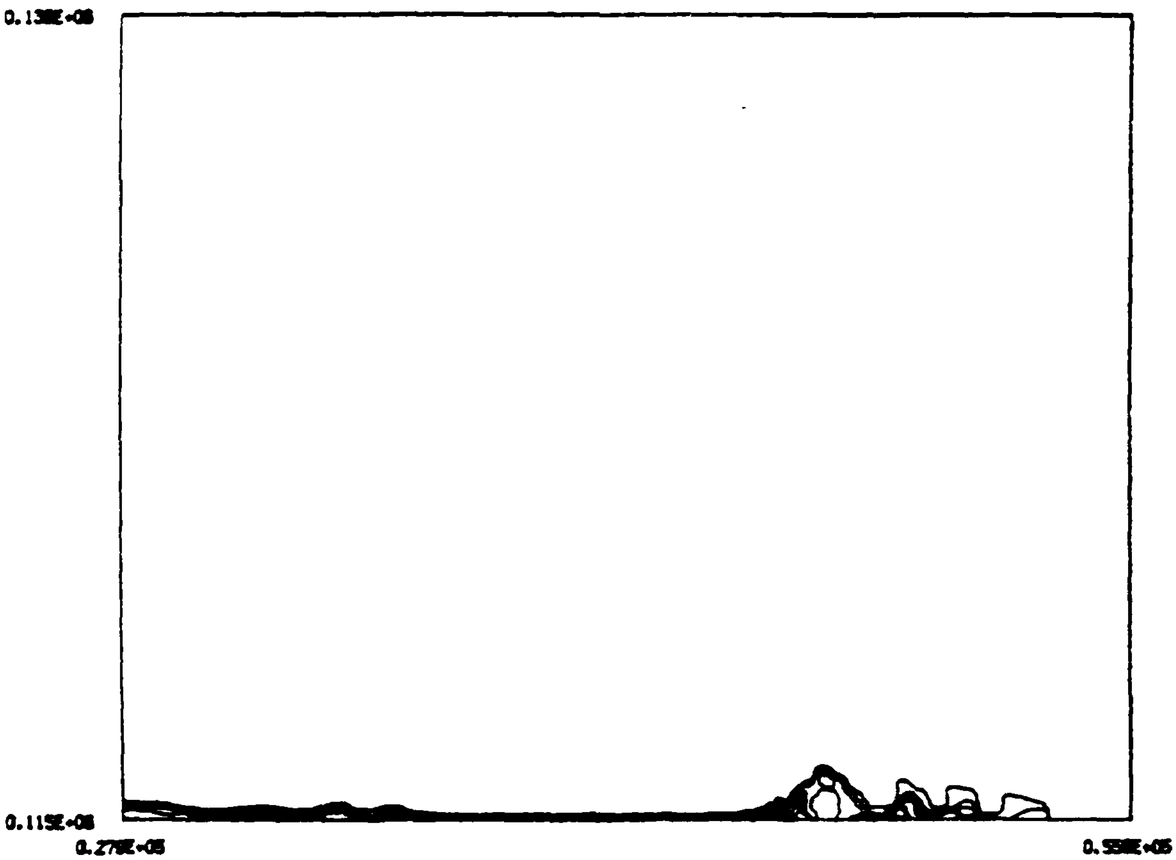


Figure 24

PRISCILLA WITH DUST

TIME= 0.46293E+00 SEC., STEP 3001. DUMP POST0031 DENSITY 2. GM/CC

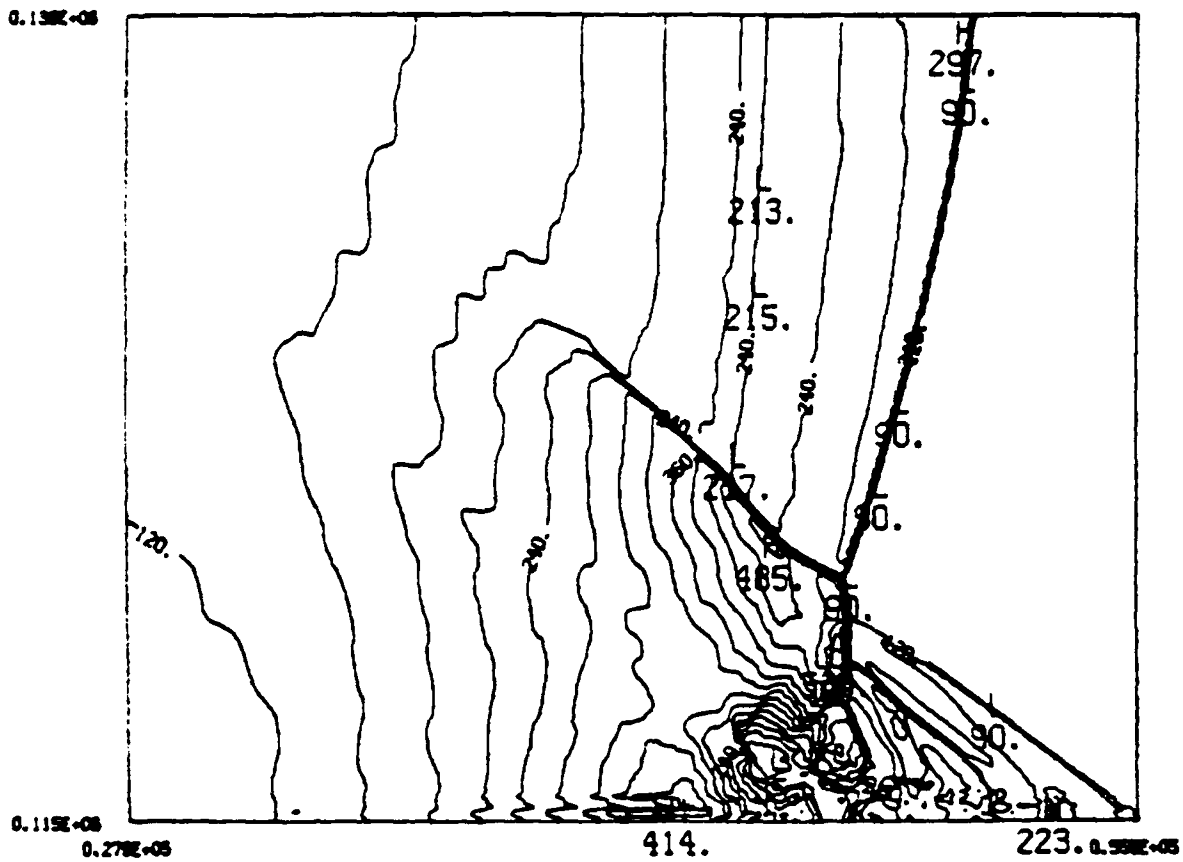


CONTOUR FROM 0.00000 TO 0.18000E-02 CONTOUR INTERVAL OF 0.10000E-03 PT(3,3)= 0.38015E-03 LABELS SCALED BY 0.10000E+06

Figure 25

PRISCILLA WITH DUST

TIME= 0.46293E+00 SEC., STEP 3001, DUMP PDST0031 PRESSURE, DYNES/CM**2

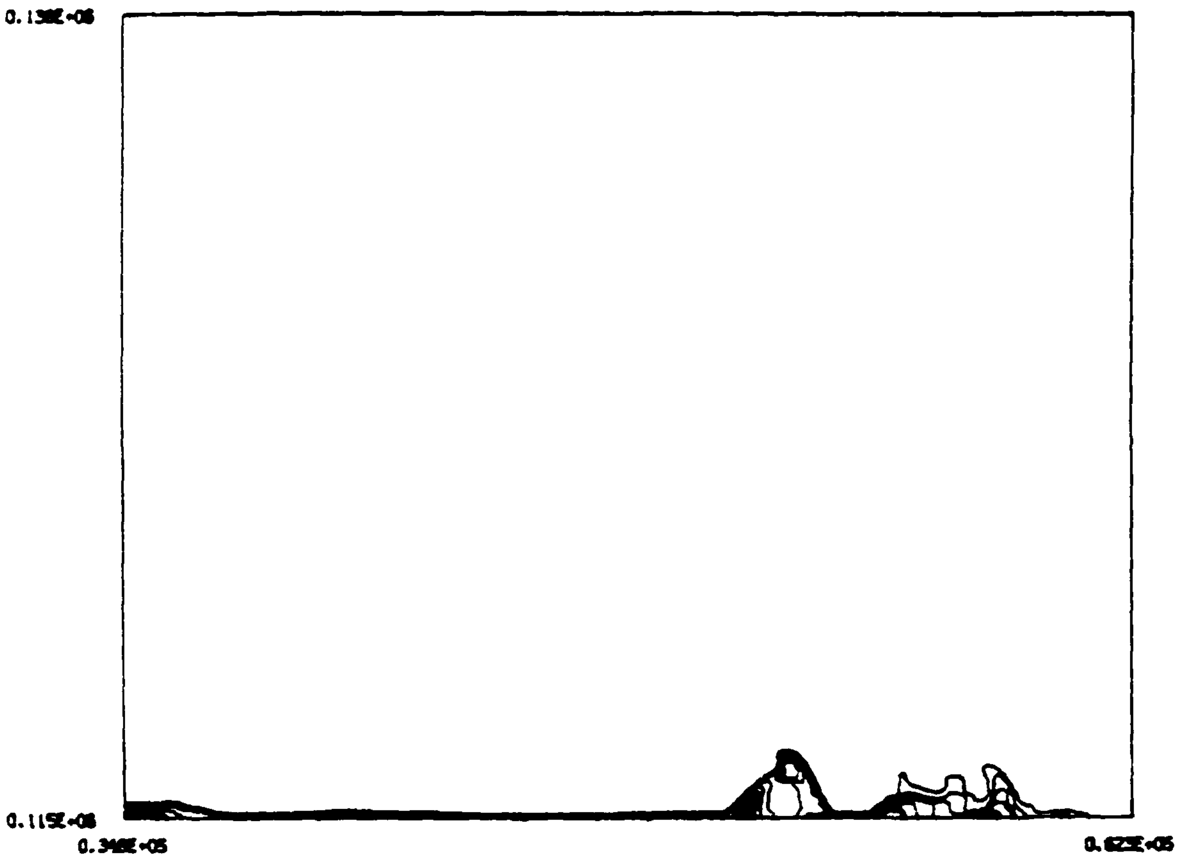


CONTOUR FROM 0.[illegible] TO 0.51000E+07 CONTOUR INTERVAL OF 0.[illegible] PT(3,3)= 0.[illegible] LABELS SCALED BY 0.[illegible]

Figure 26

PRISCILLA WITH DUST

TIME= 0.56632E+00 SEC.. STEP 3501. DUMP PDST0036   DENSITY 2. GM/CC

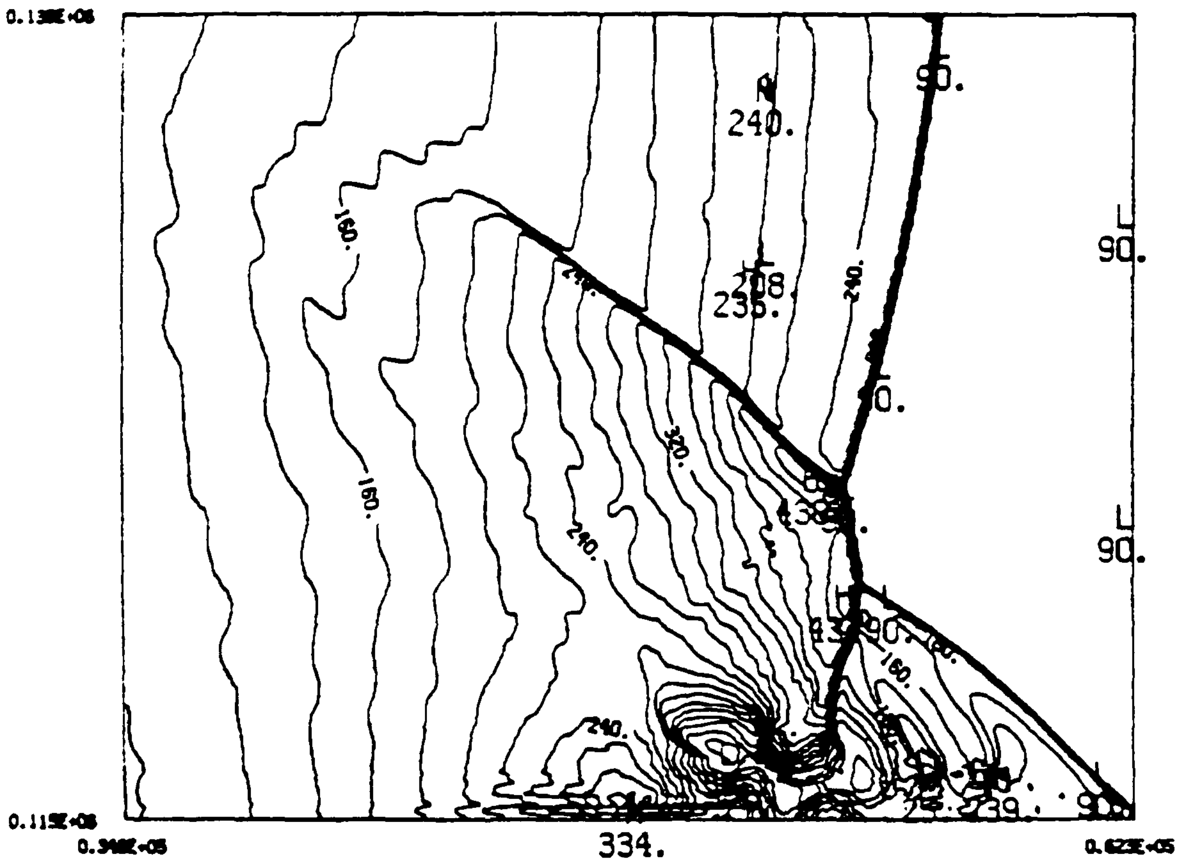


CONTOUR FROM 0.00000 TO 0.17000E-02 CONTOUR INTERVAL OF 0.10000E-03 PT(3,3)= 0.35139E-03 LABELS SCALED BY 0.10000E+05

Figure 27

PRISCILLA WITH DUST

TIME= 0.56632E+00 SEC.. STEP 3501. DUMP POST0036 PRESSURE. DYNES/CM**2



CONTOUR FROM 0.20000E+06 TO 0.43000E+07 CONTOUR INTERVAL OF 0.20000E+06 PT(3,3)= 0.88604E+06 LABELS SCALED BY 0.10000E-03

Figure 28

PRISCILLA WITH DUST

TIME= 0.56632E+00 SEC., STEP 3501. DUMP PDST0036 DENSITY 1. GM/CC

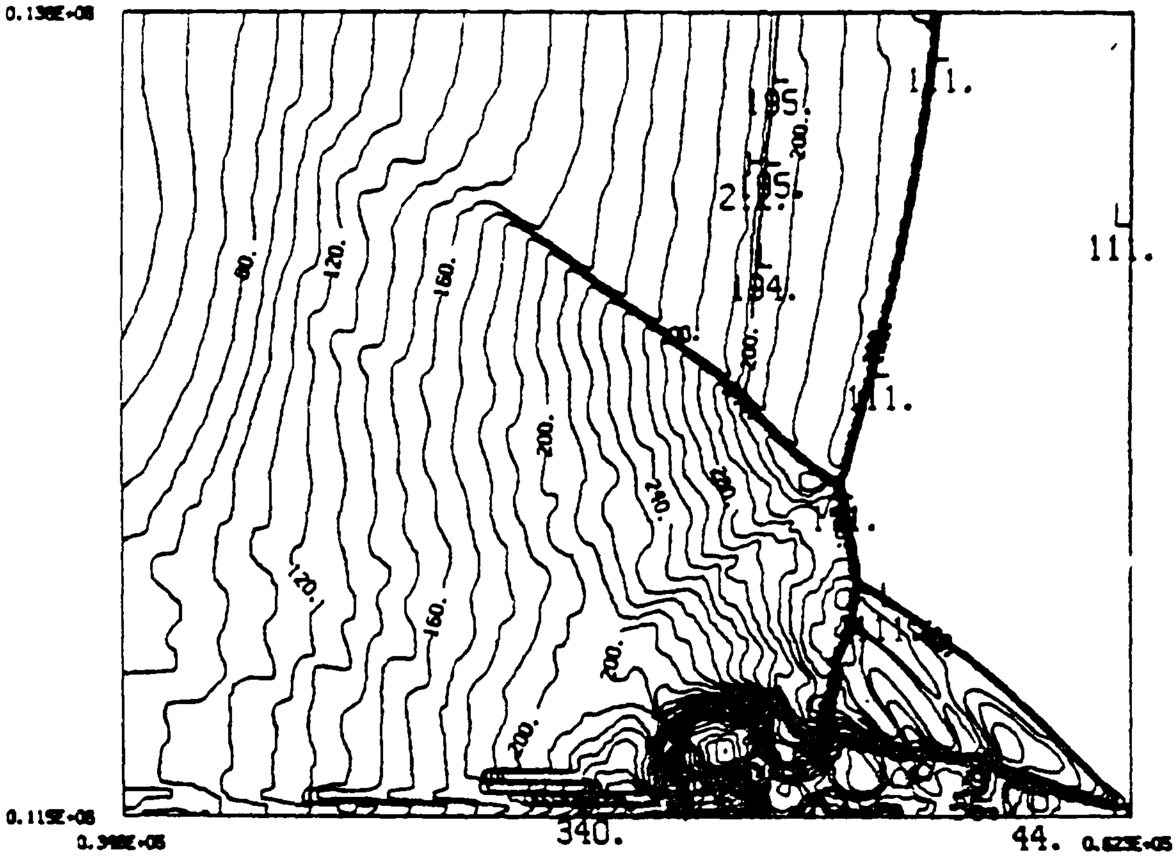


Figure 29

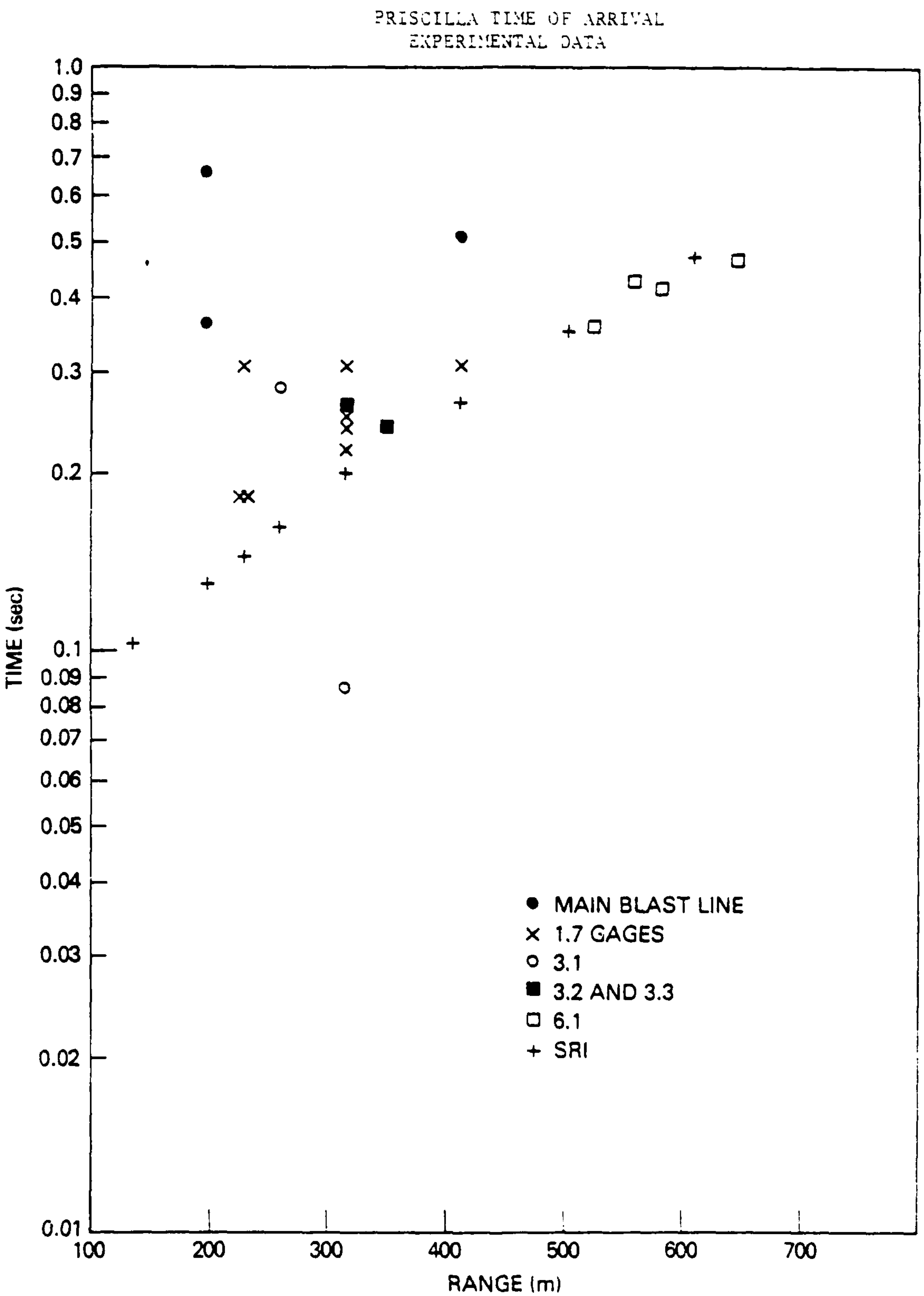
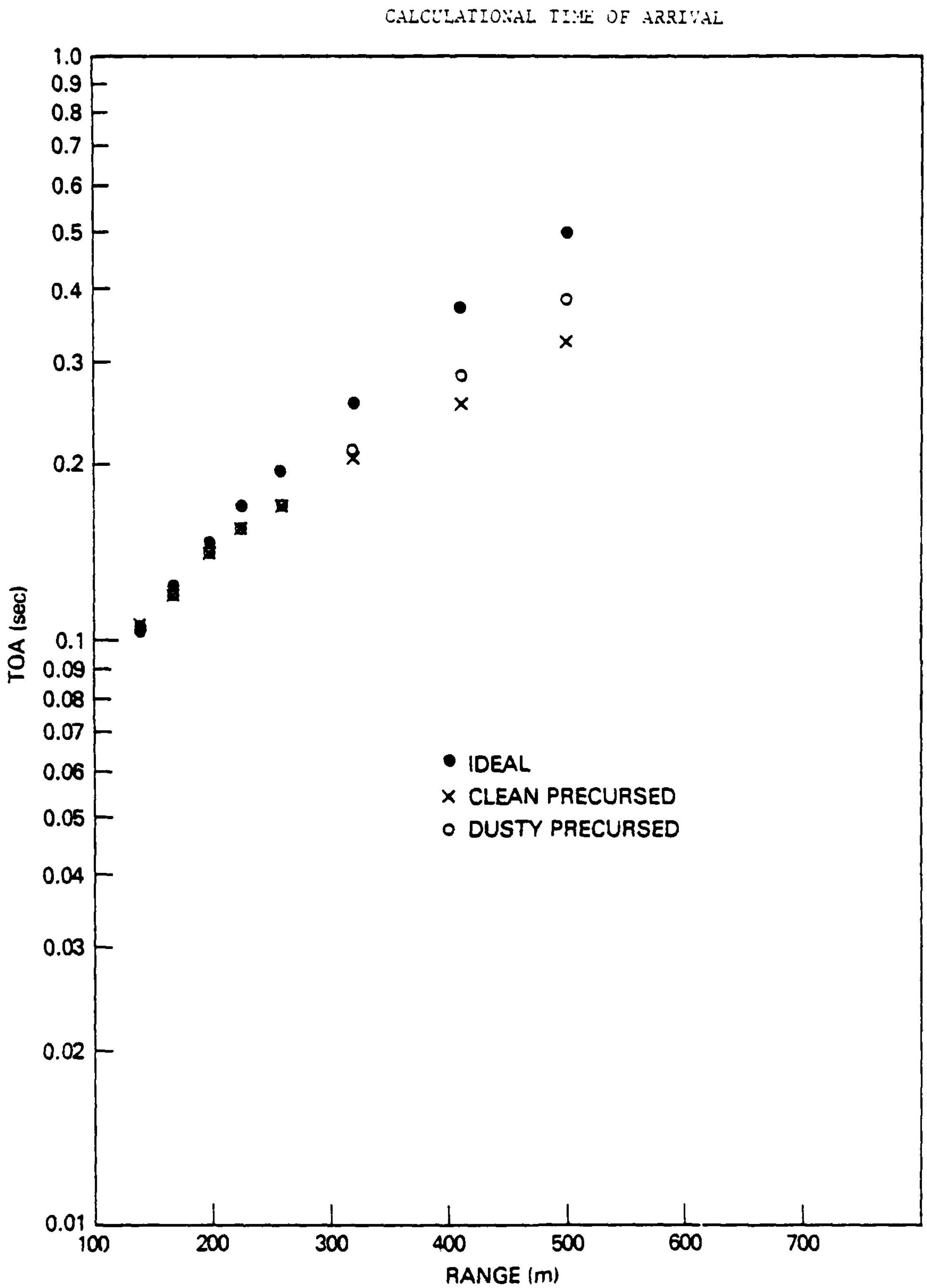

PRISCILLA TIME OF ARRIVAL
EXPERIMENTAL DATA
TIME (sec)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
100
200
300
400
500
600
700
RANGE (m)
MAIN BLAST LINE
1.7 GAGES
3.1
3.2 AND 3.3
6.1
SRI

Figure 30a



CALCULATIONAL TIME OF ARRIVAL
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
TOA (sec)
IDEAL
CLEAN PRECURSED
DUSTY PRECURSED
100
200
300
400
500
600
700
RANGE (m)

Figure 30b

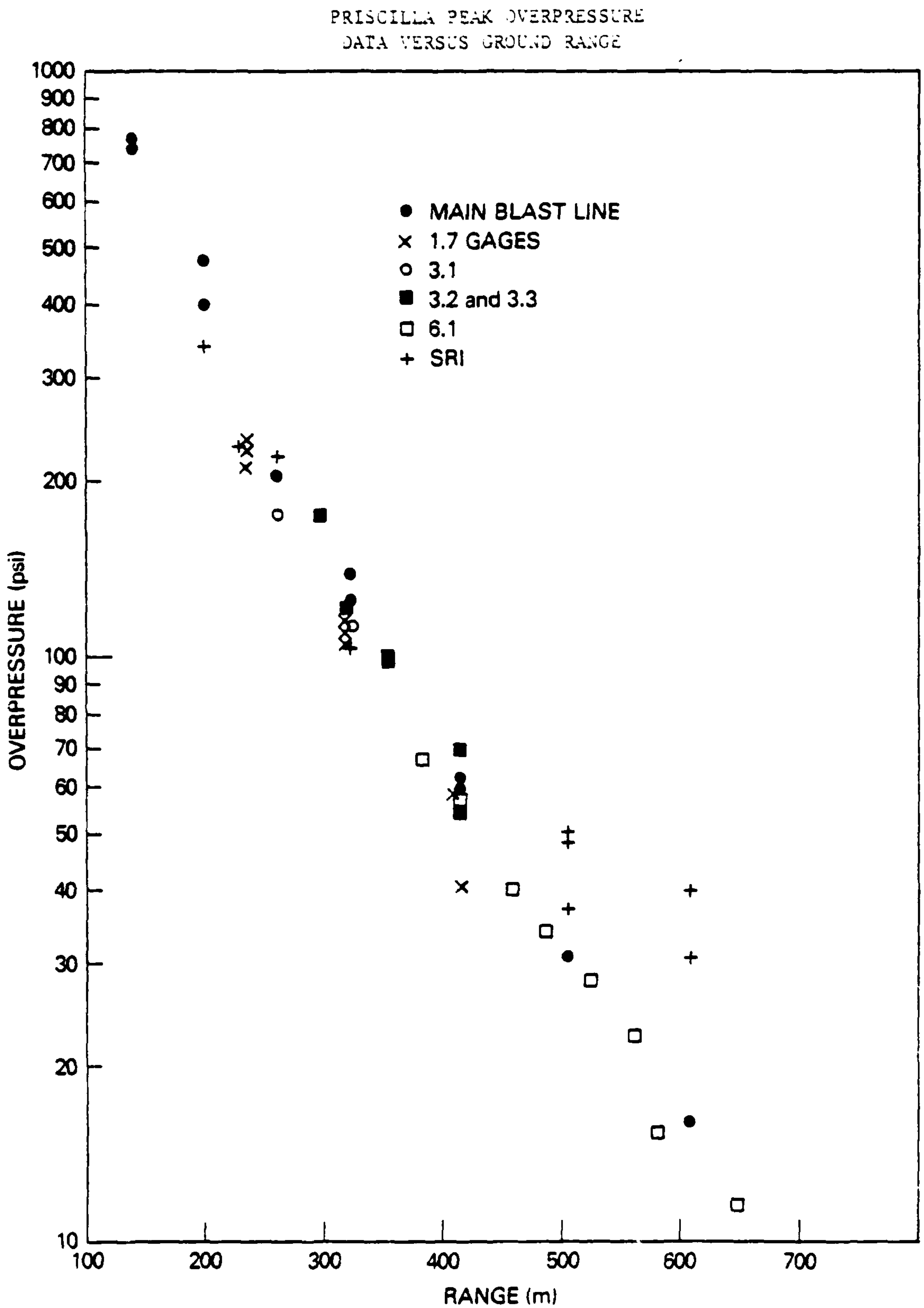

PRISCILLA PEAK OVERPRESSURE
DATA VERSUS GROUND RANGE
MAIN BLAST LINE
1.7 GAGES
3.1
3.2 and 3.3
6.1
SRI
OVERPRESSURE (psi)
RANGE (m)
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
100
200
300
400
500
600
700

Figure 31a

CALCULATIONAL PEAK OVERPRESSURE
VERSUS GROUND RANGE

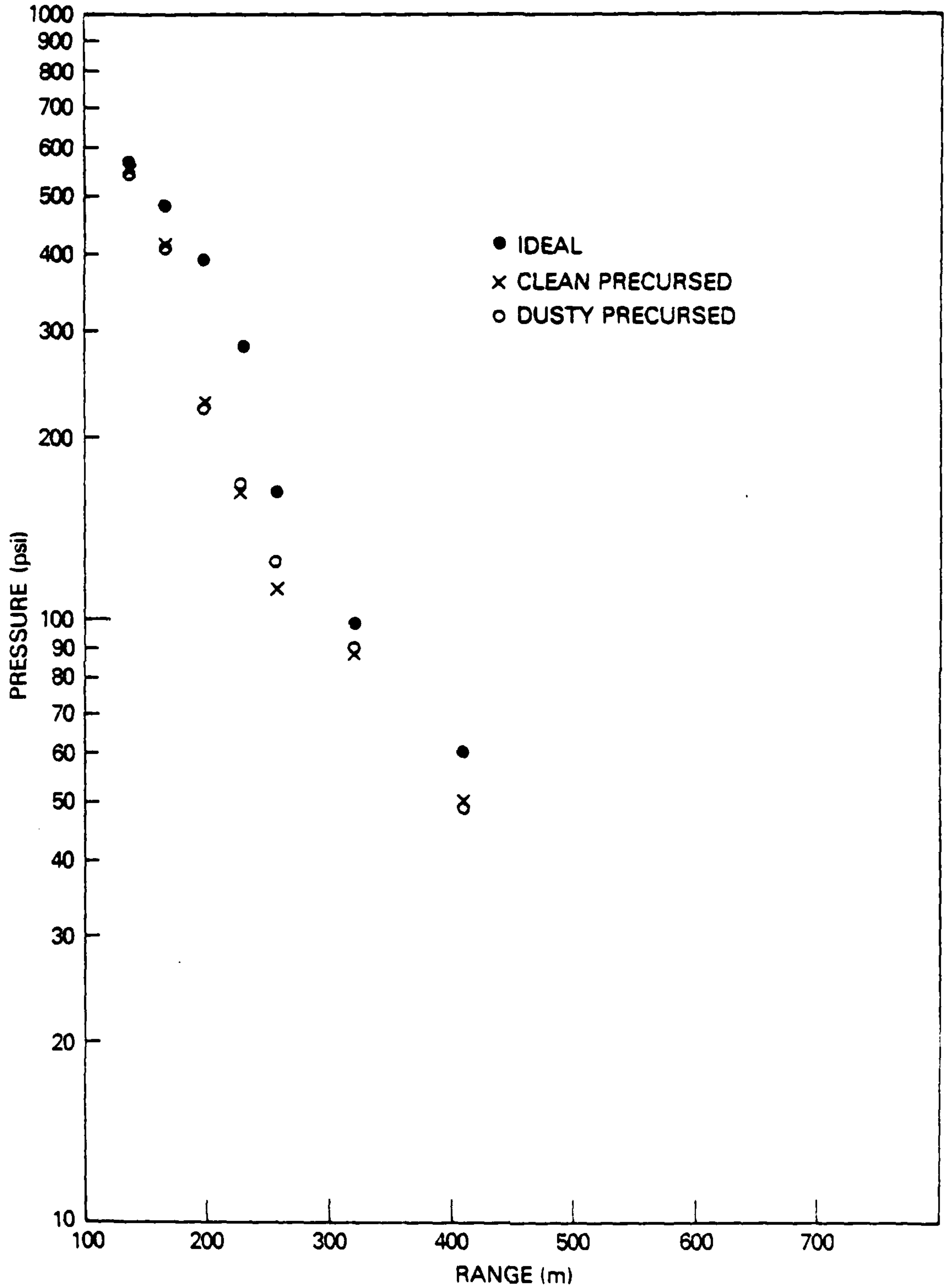


Figure 31b

PRISCILLA DYNAMIC PRESSURE DATA
VERSUS GROUND RANGE

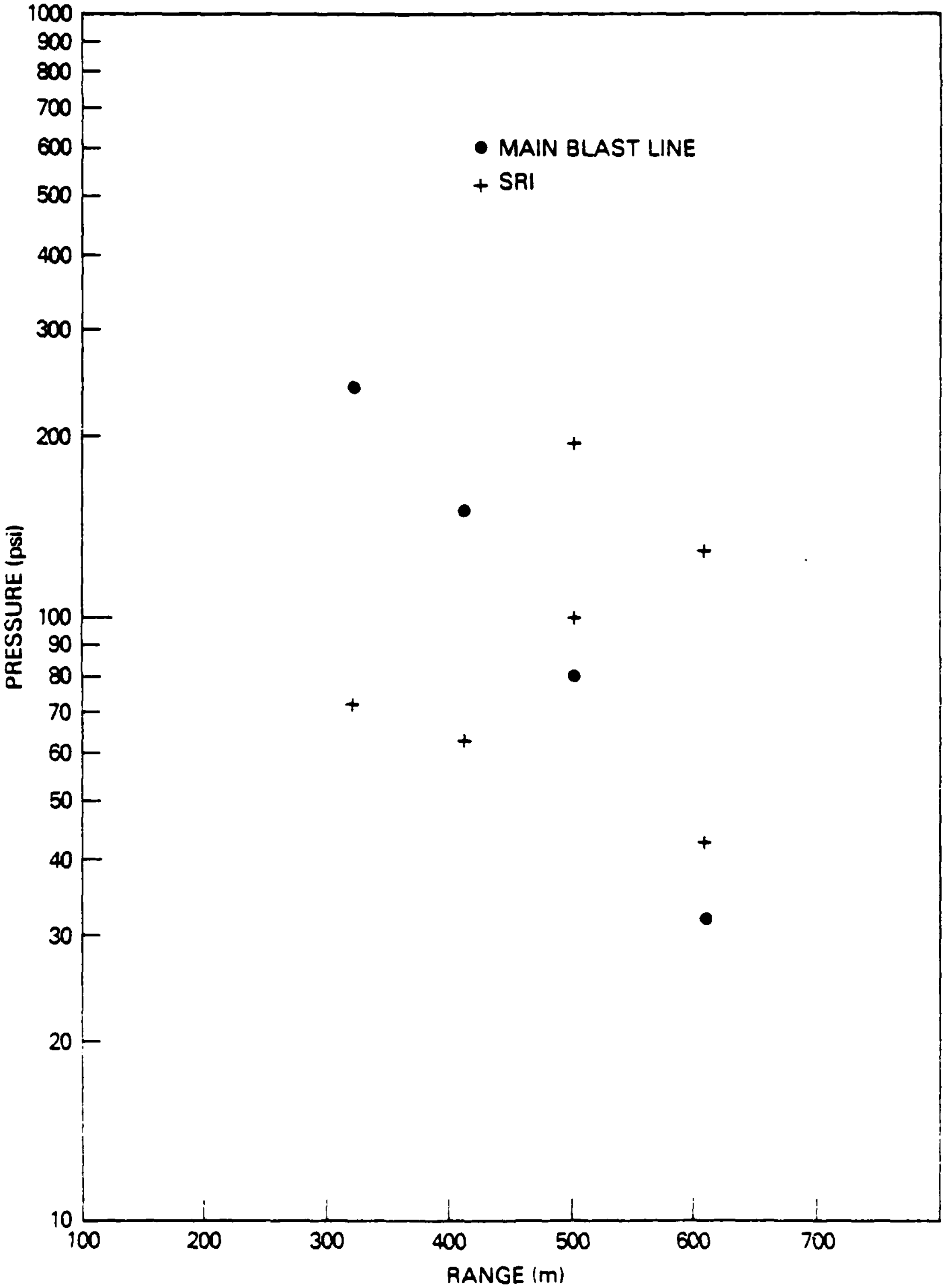


Figure 32a

CALCULATIONAL DYNAMIC PRESSURE
VERSUS GROUND RANGE

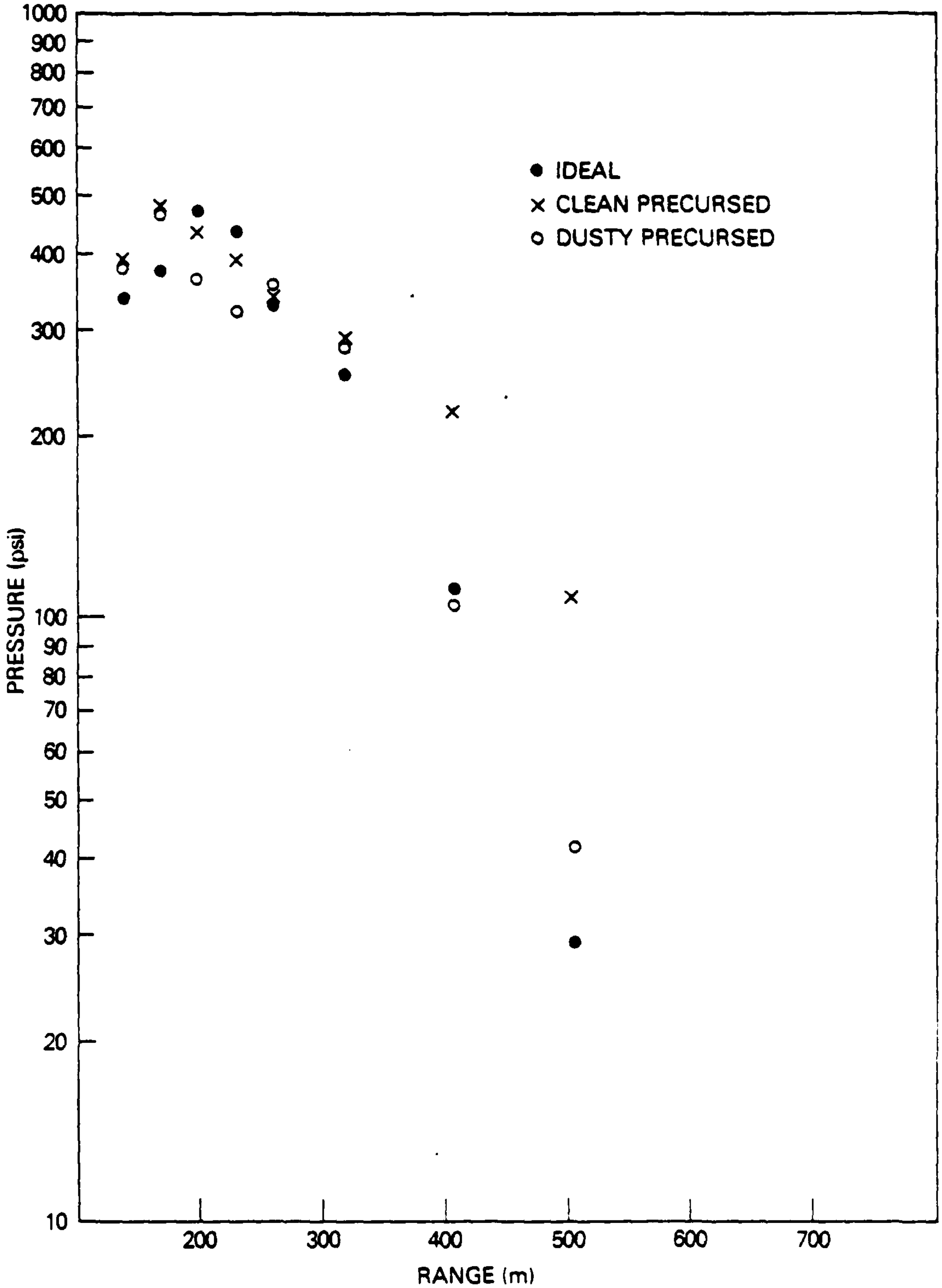
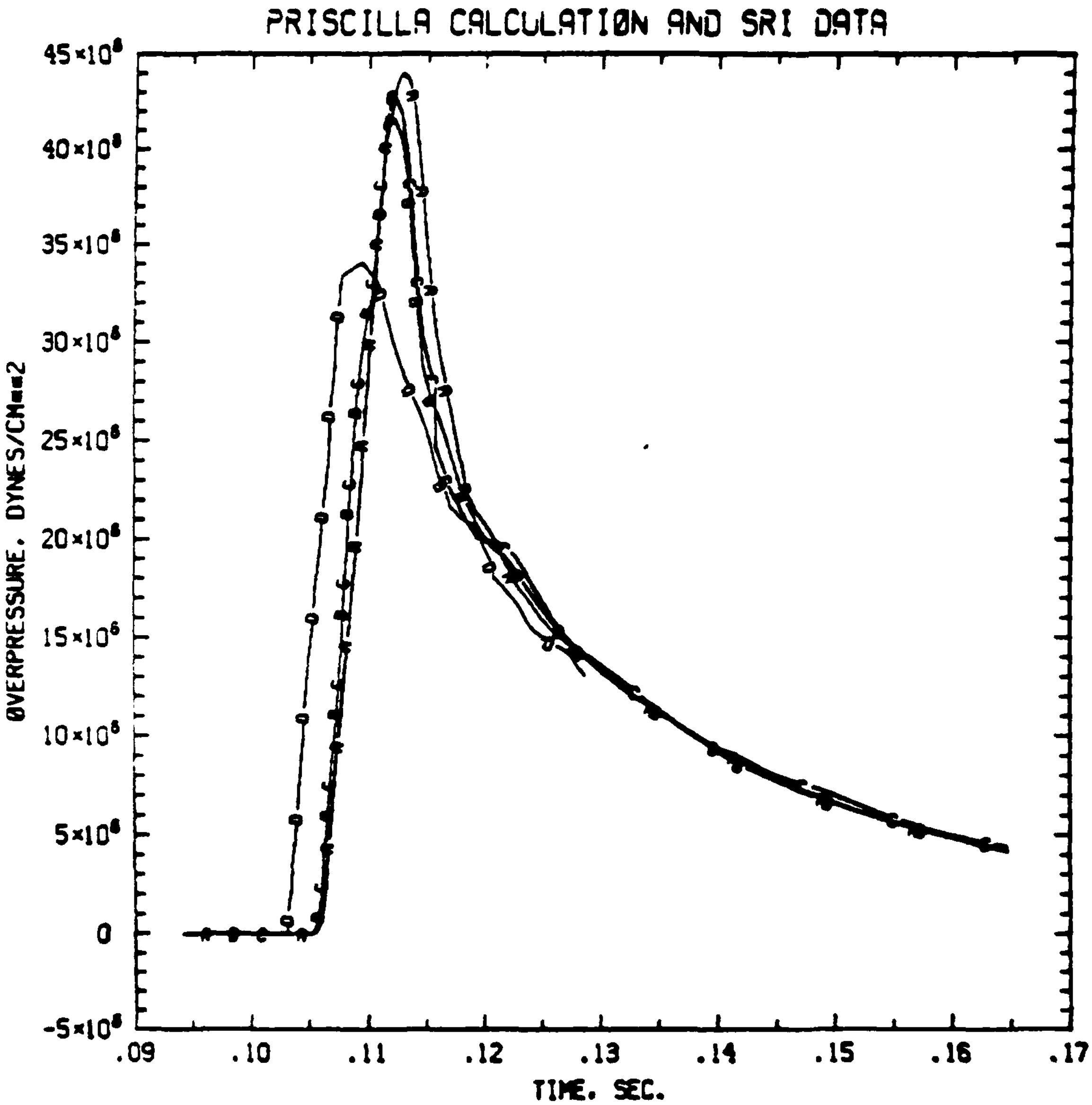
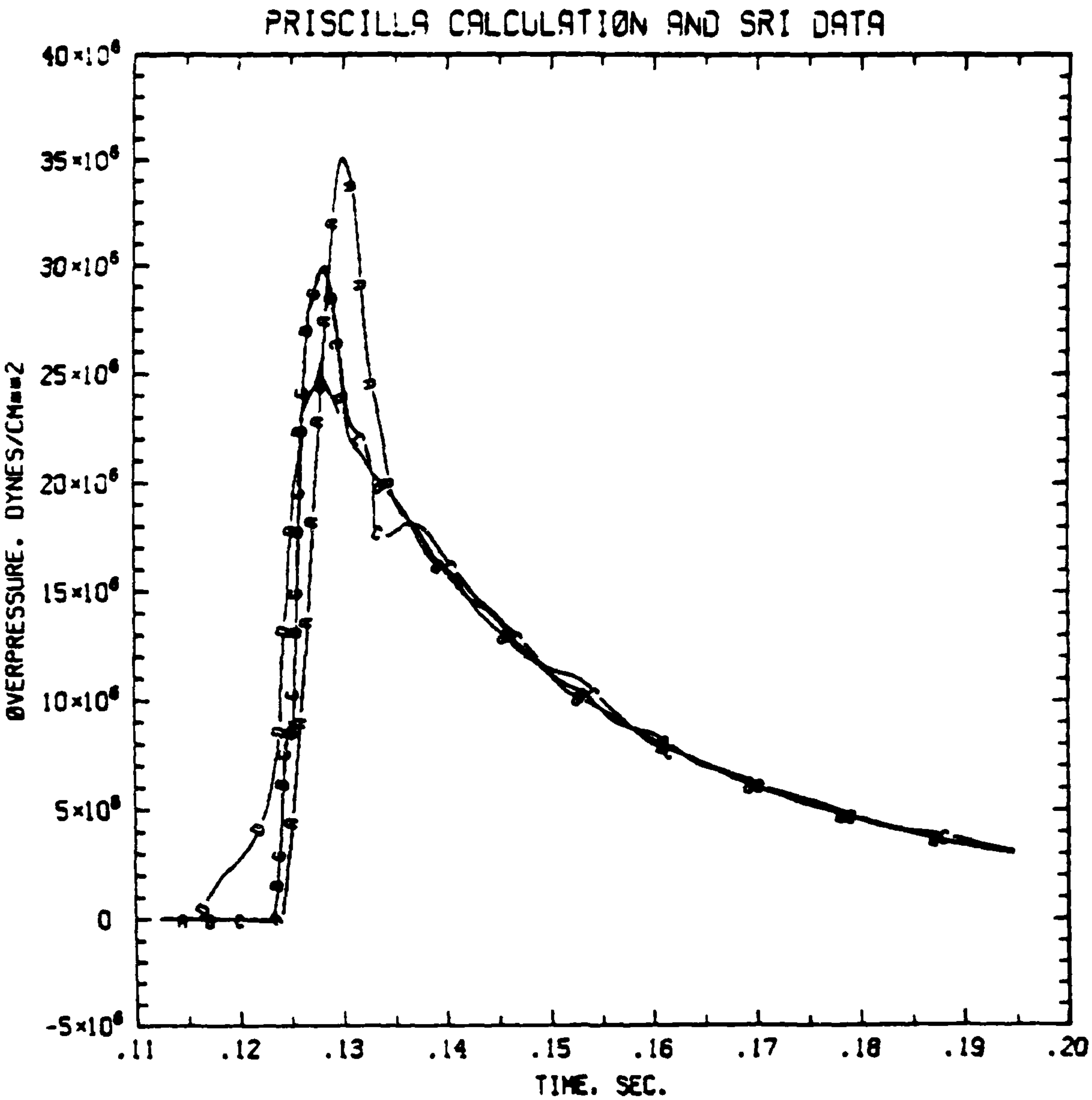


Figure 32b



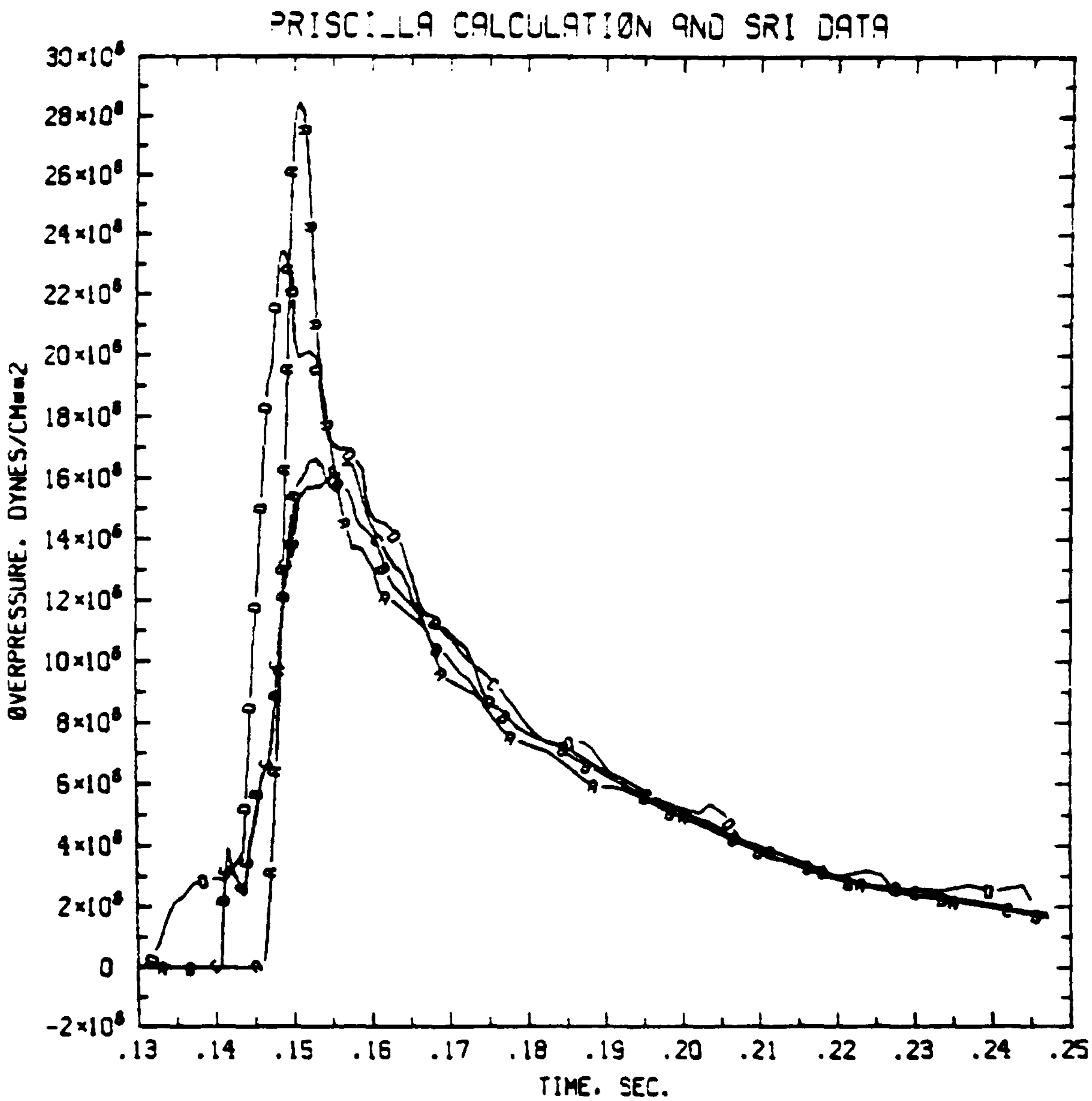
XS YS = 0.45000E+03 0.00000E+00 FT

Figure 33



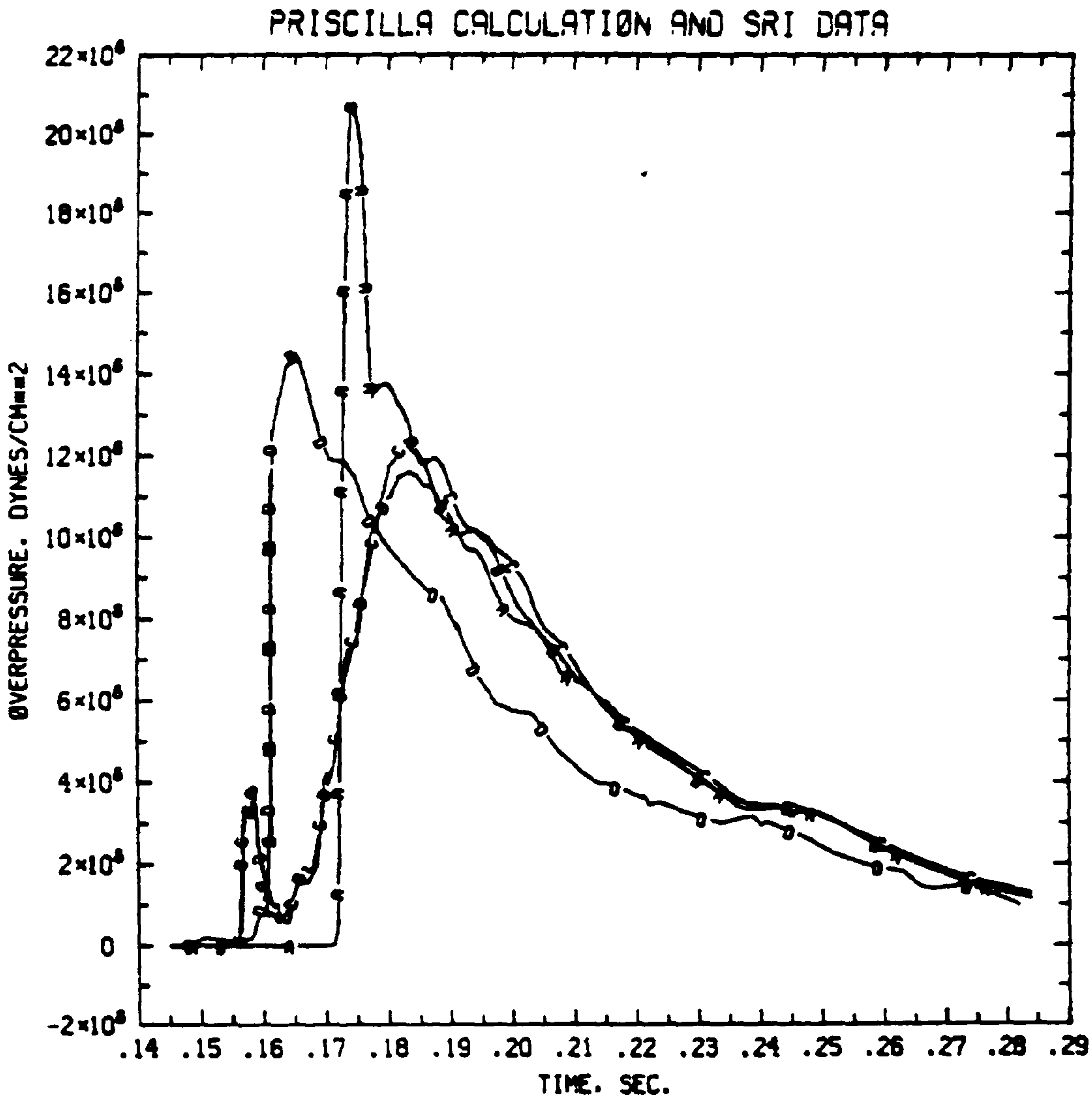
XS,YS = 0.55000E+03 0.00000E+00 FT.

Figure 34



XS,YS = 0.65000E+03 0.00000E+00 FT.

Figure 35



XS.YS = 0.75000E+03 0.00000E+00 FT.

Figure 36

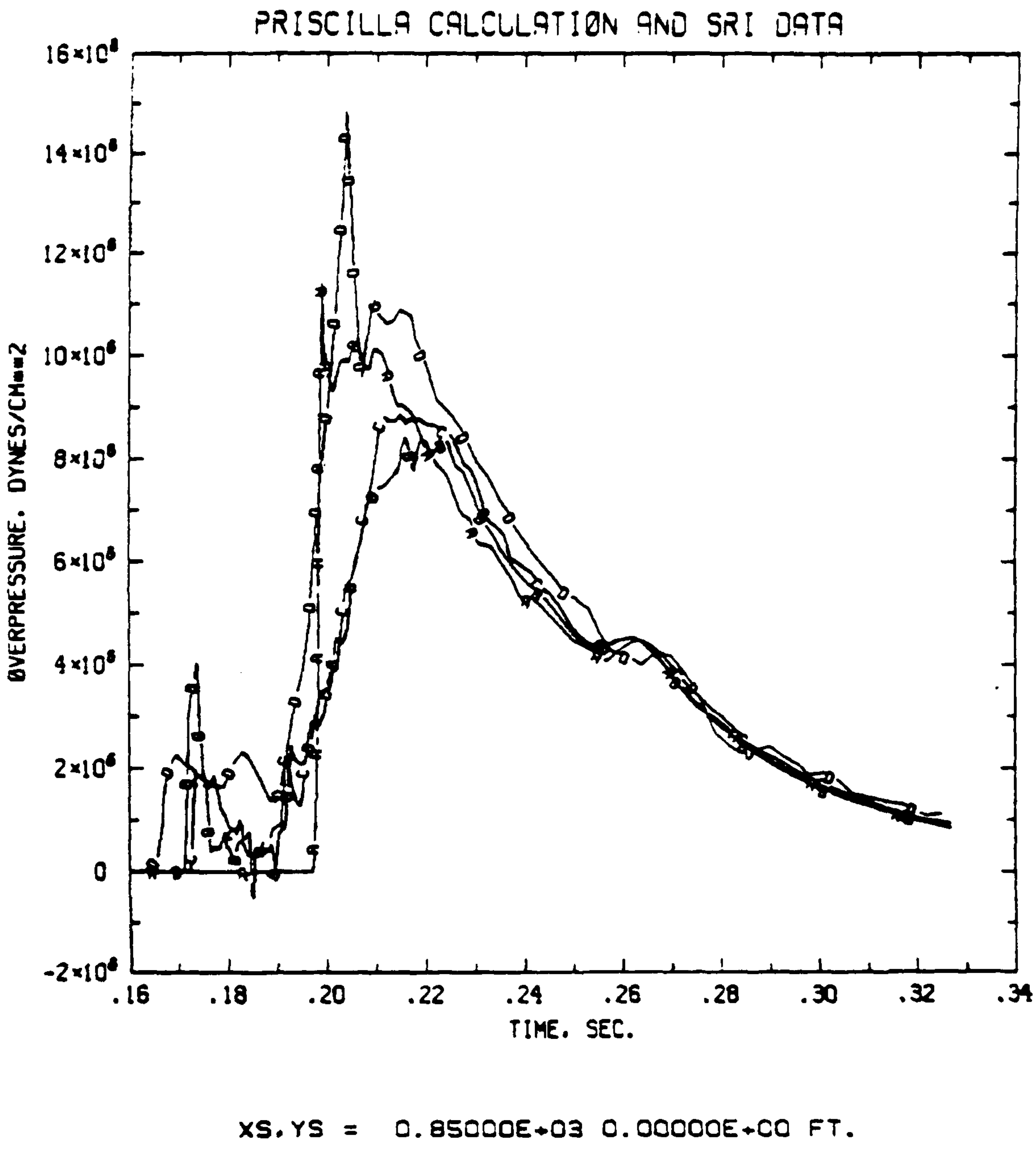
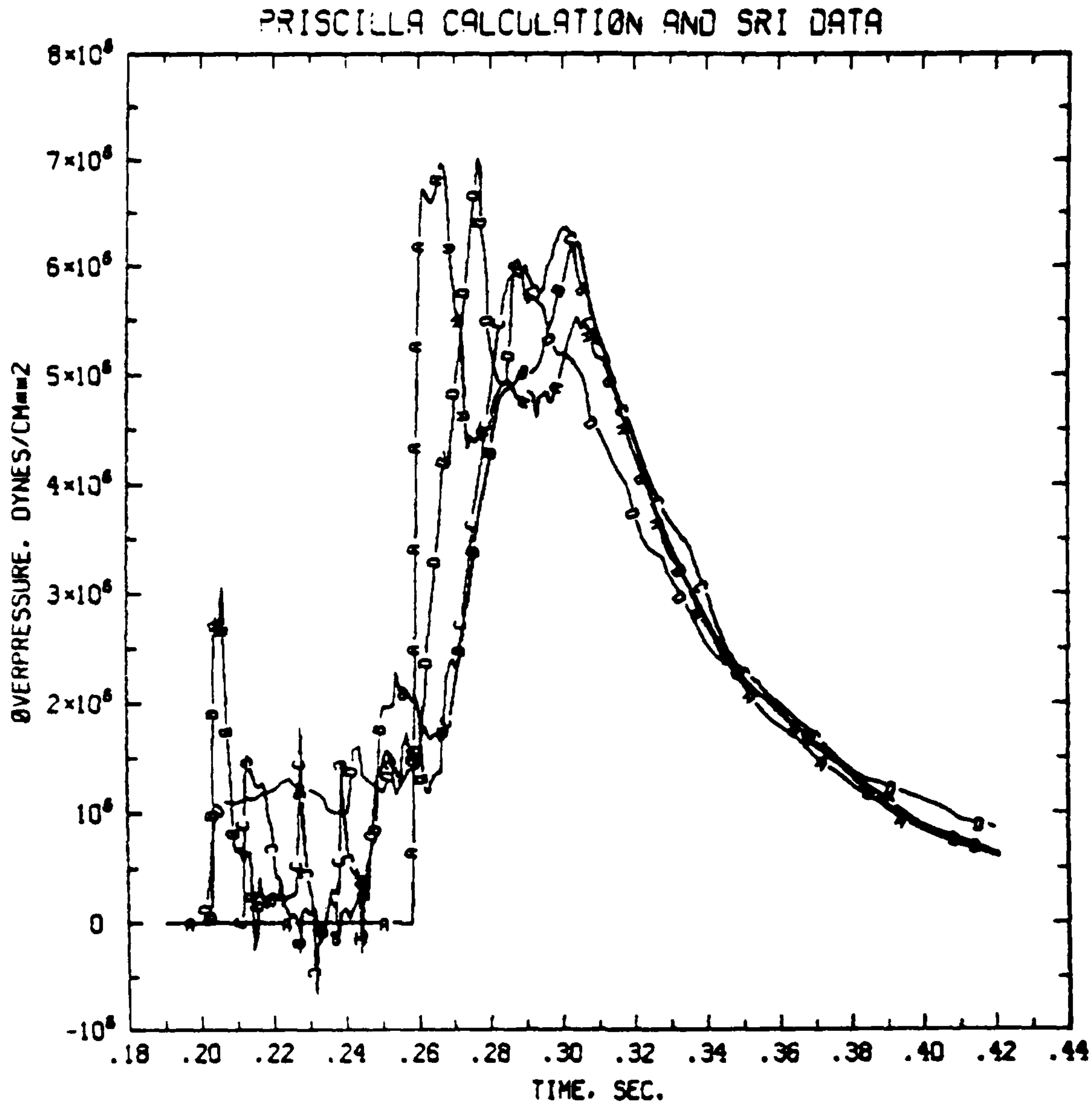

PRISCILLA CALCULATION AND SRI DATA
16×10⁶
14×10⁶
12×10⁶
10×10⁶
8×10⁶
6×10⁶
4×10⁶
2×10⁶
0
-2×10⁶
OVERPRESSURE, DYNES/CM**2
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
TIME, SEC.
XS,YS = 0.85000E+03 0.00000E+00 FT.

Figure 37



XS.YS = 0.10500E+04 0.00000E+00 FT.

Figure 38

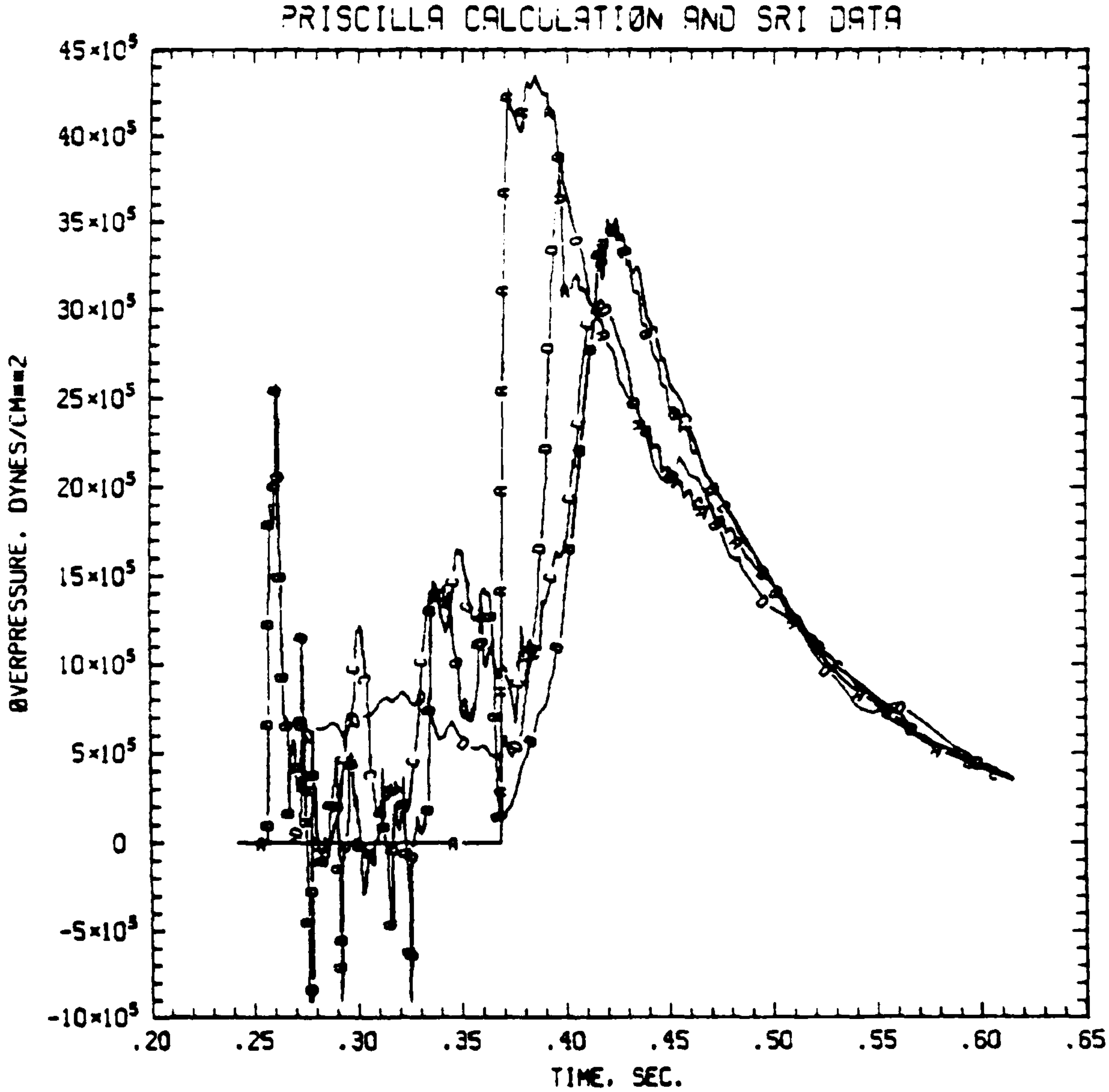
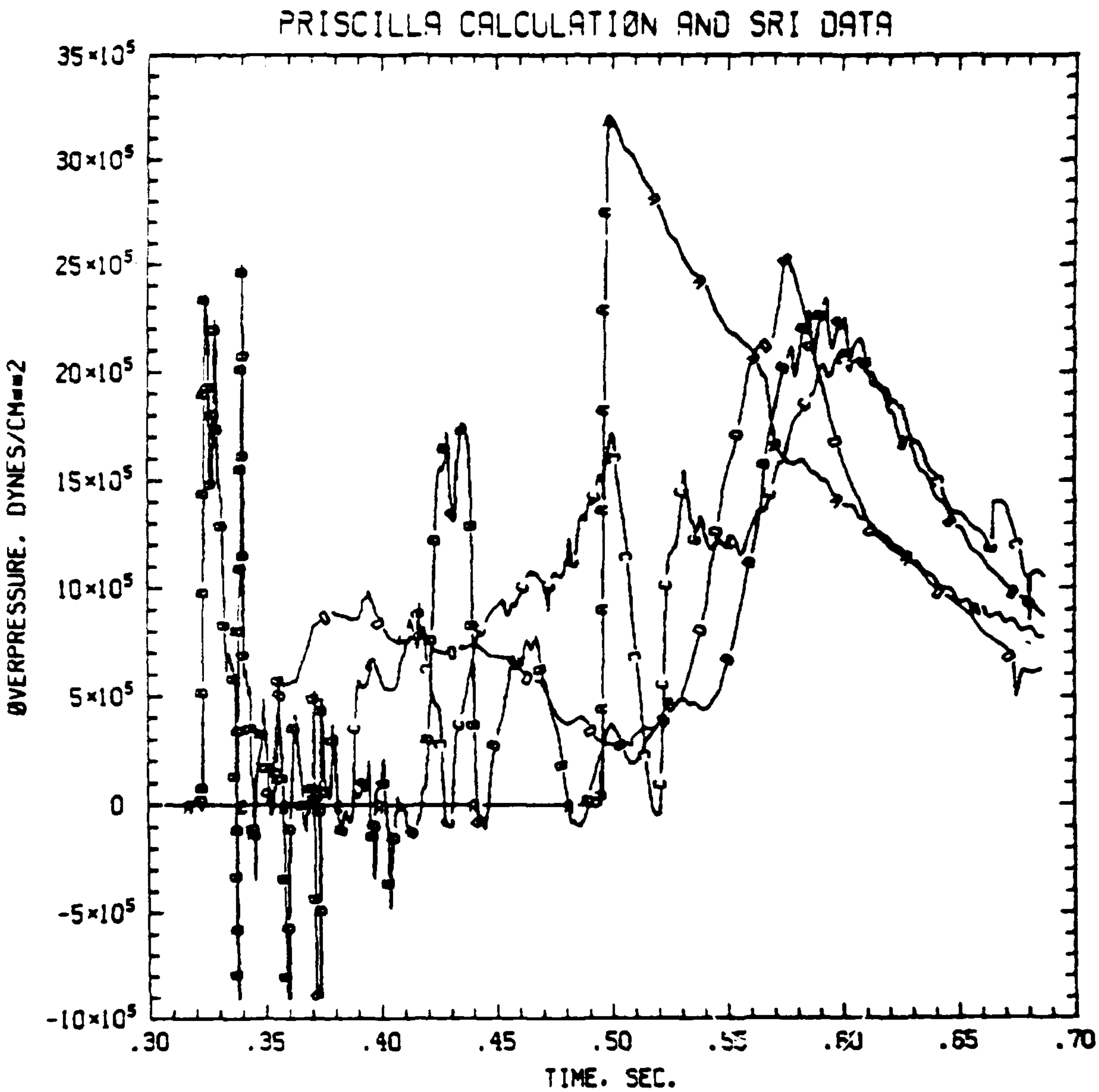

PRISCILLA CALCULATION AND SRI DATA
45×10^5
40×10^5
35×10^5
30×10^5
25×10^5
20×10^5
15×10^5
10×10^5
5×10^5
0
-5×10^5
-10×10^5
ØVERPRESSURE, DYNES/CM**2
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65
TIME, SEC.

Figure 39



XS, YS = 0.16500E-04 0.00000E+00 FT

Figure 40

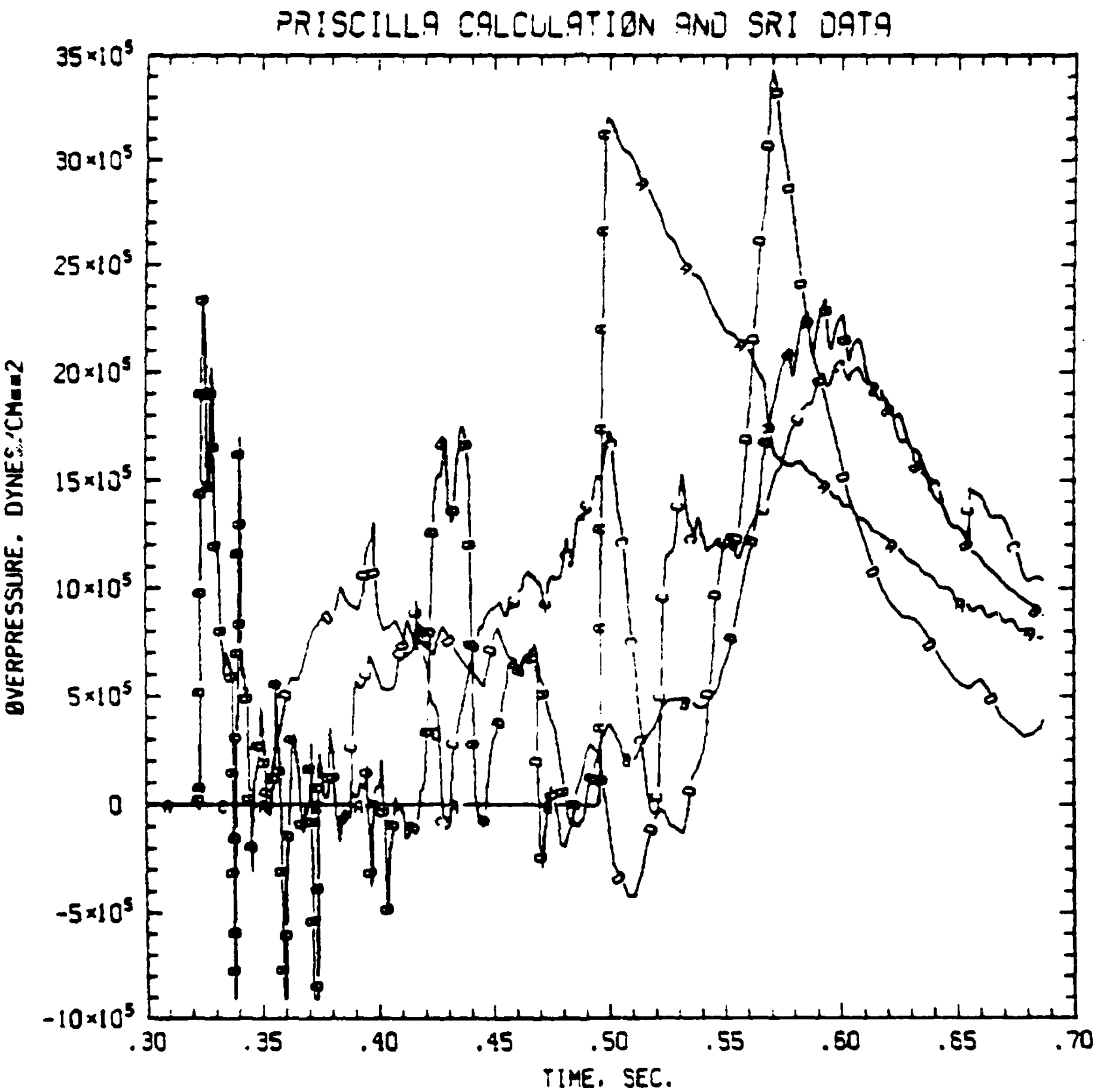
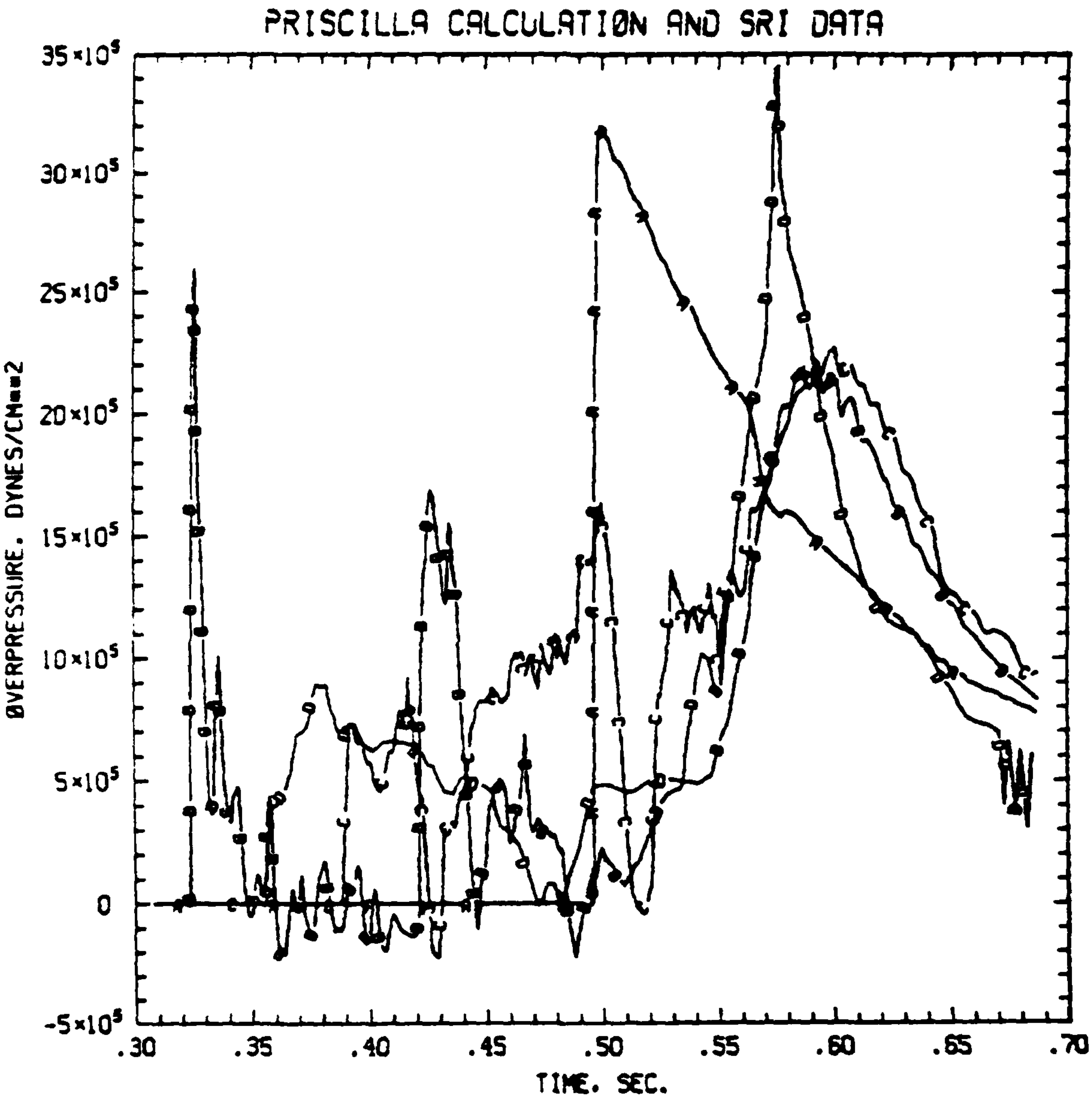
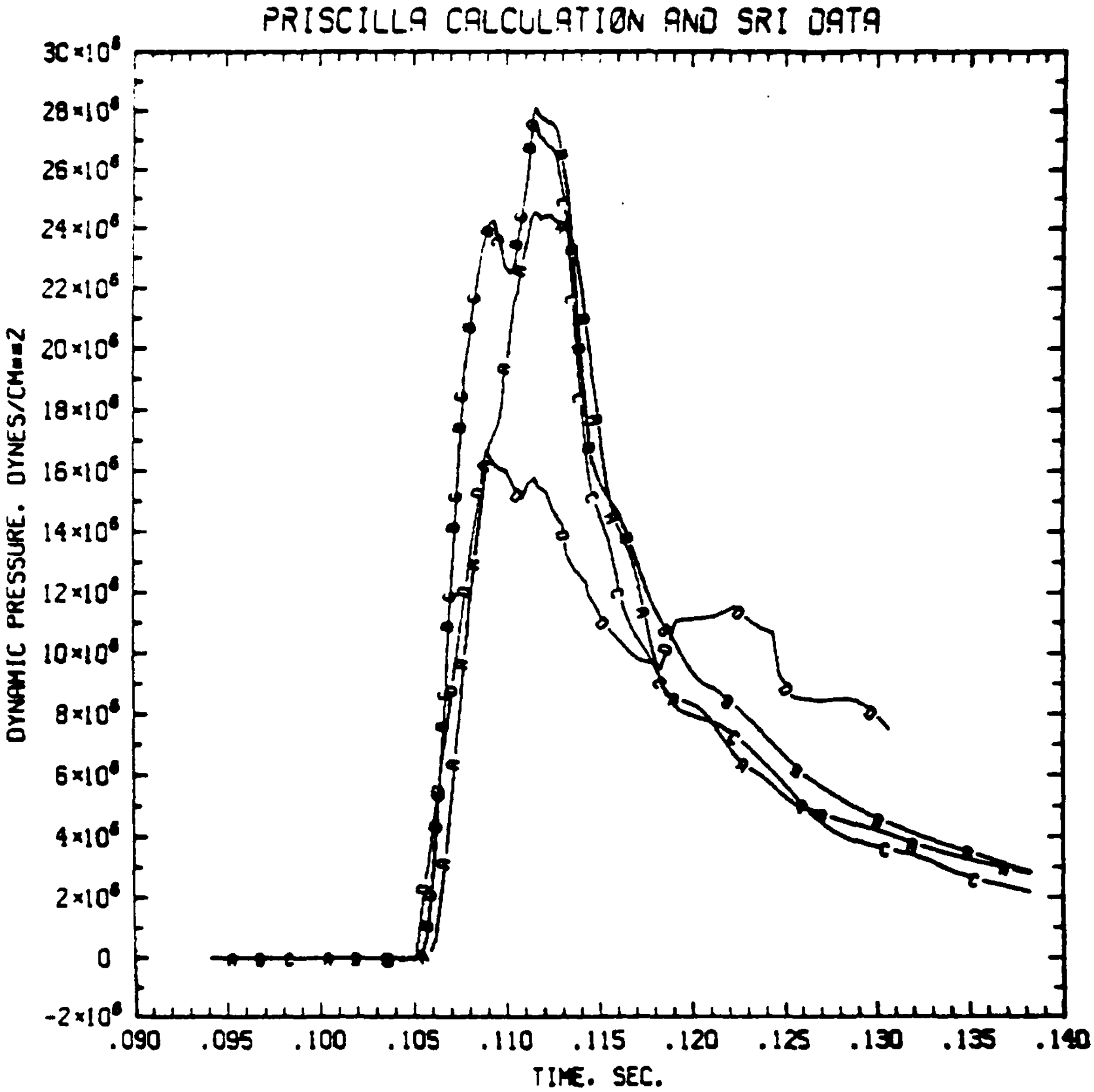

PRISCILLA CALCULATION AND SRI DATA
OVERPRESSURE, DYNES/CM**2
TIME, SEC.
35×10^5
30×10^5
25×10^5
20×10^5
15×10^5
10×10^5
5×10^5
0
-5×10^5
-10×10^5
.30
.35
.40
.45
.50
.55
.60
.65
.70

Figure 41



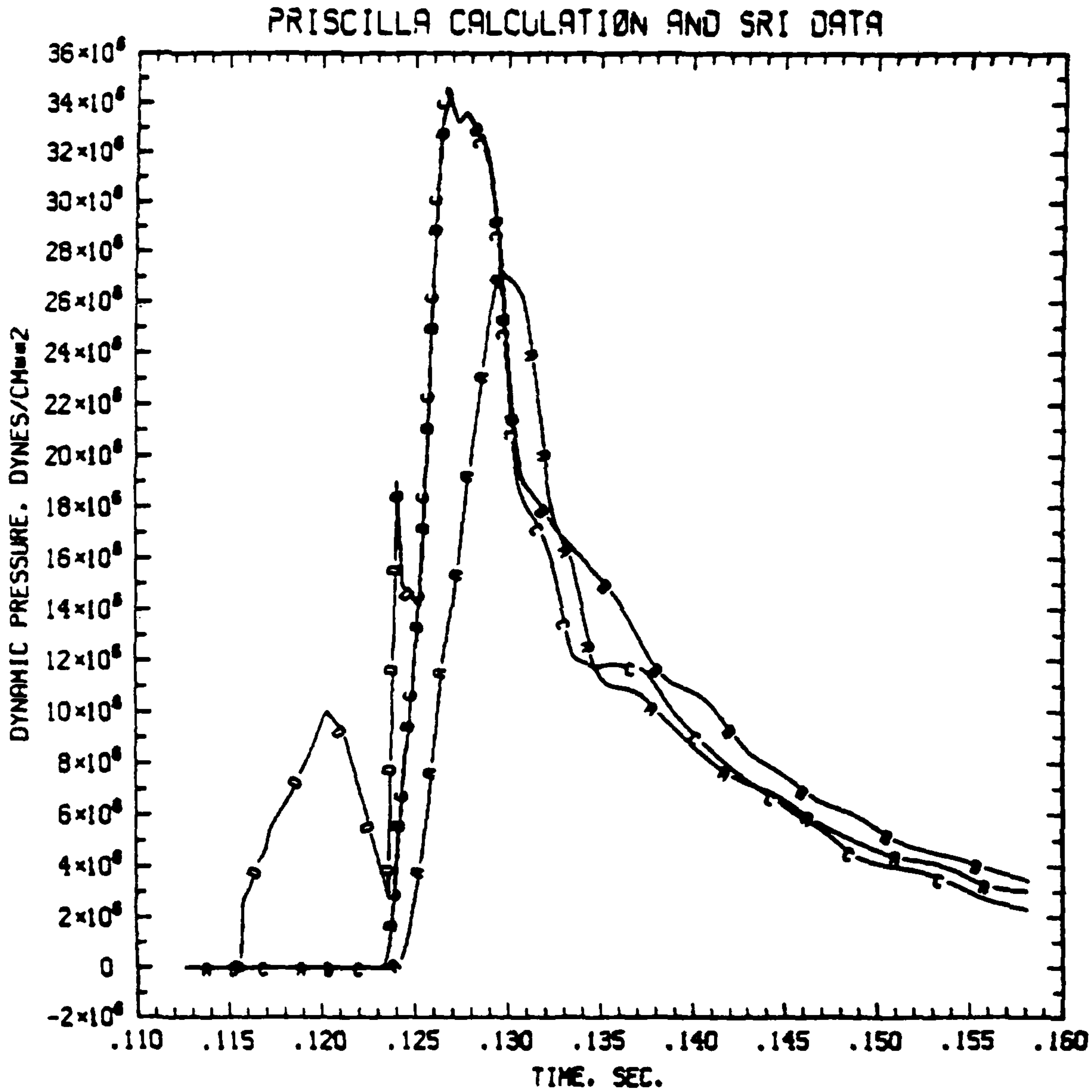
XS,YS = 0.16500E+04 0.10000E+02 FT

Figure 42



XS.YS = 0.45000E+03 0.30000E+01 FT.

Figure 43



XS,YS = 0.55000E+03 0.30000E+01 FT.

Figure 44

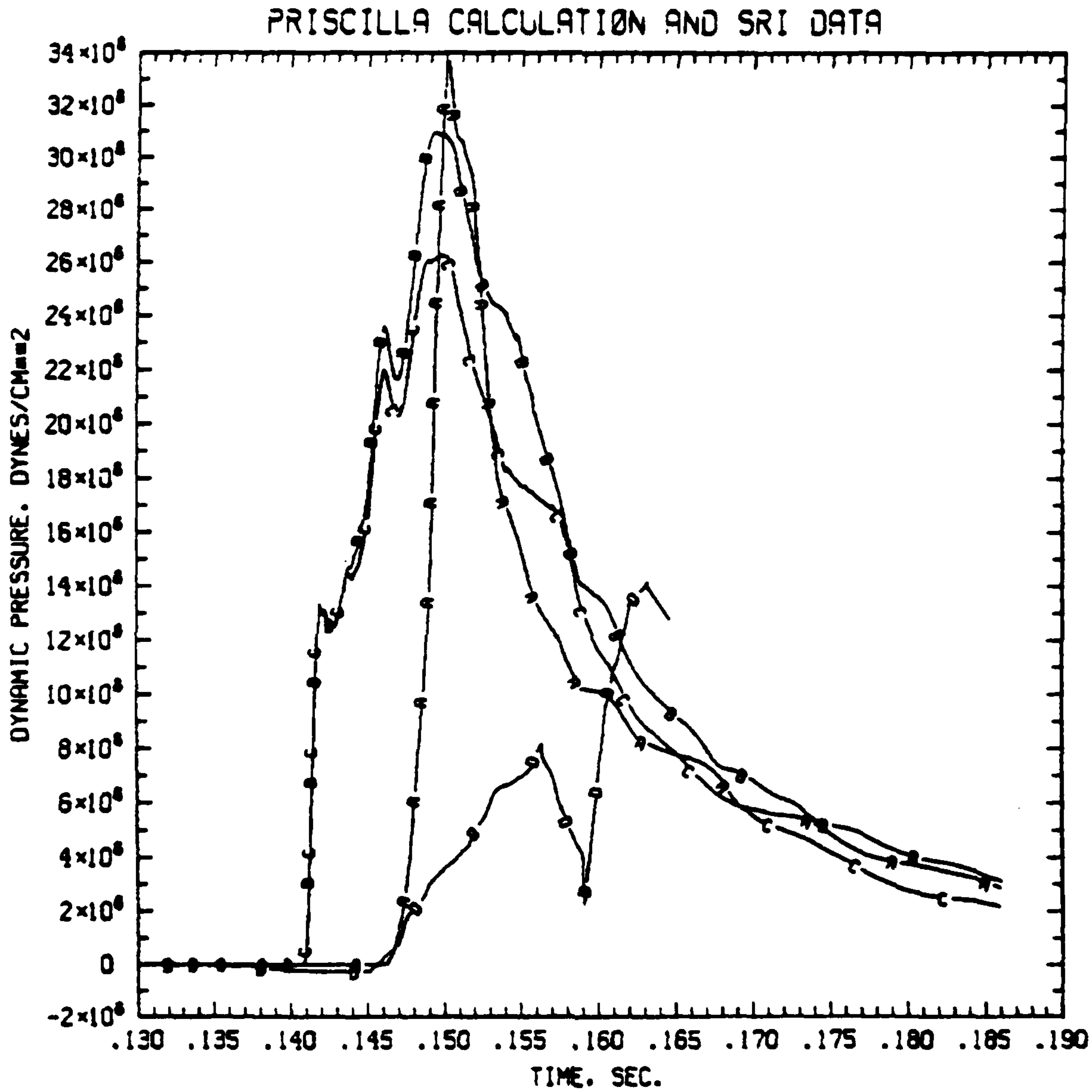

PRISCILLA CALCULATION AND SRI DATA
DYNAMIC PRESSURE, DYNES/CM**2
34×10^6
32×10^6
30×10^6
28×10^6
26×10^6
24×10^6
22×10^6
20×10^6
18×10^6
16×10^6
14×10^6
12×10^6
10×10^6
8×10^6
6×10^6
4×10^6
2×10^6
0
-2×10^6
.130 .135 .140 .145 .150 .155 .160 .165 .170 .175 .180 .185 .190
TIME, SEC.

Figure 45

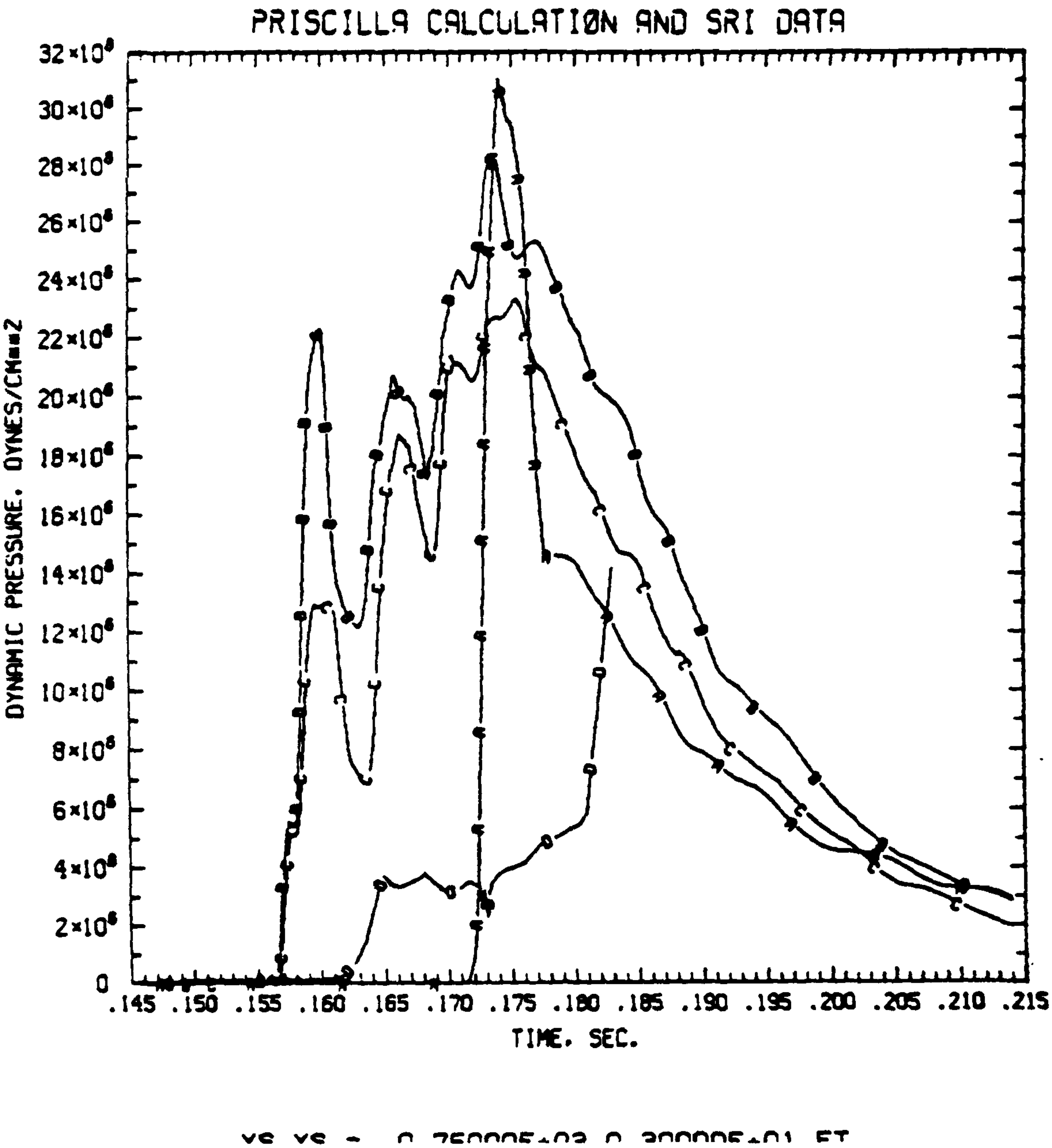
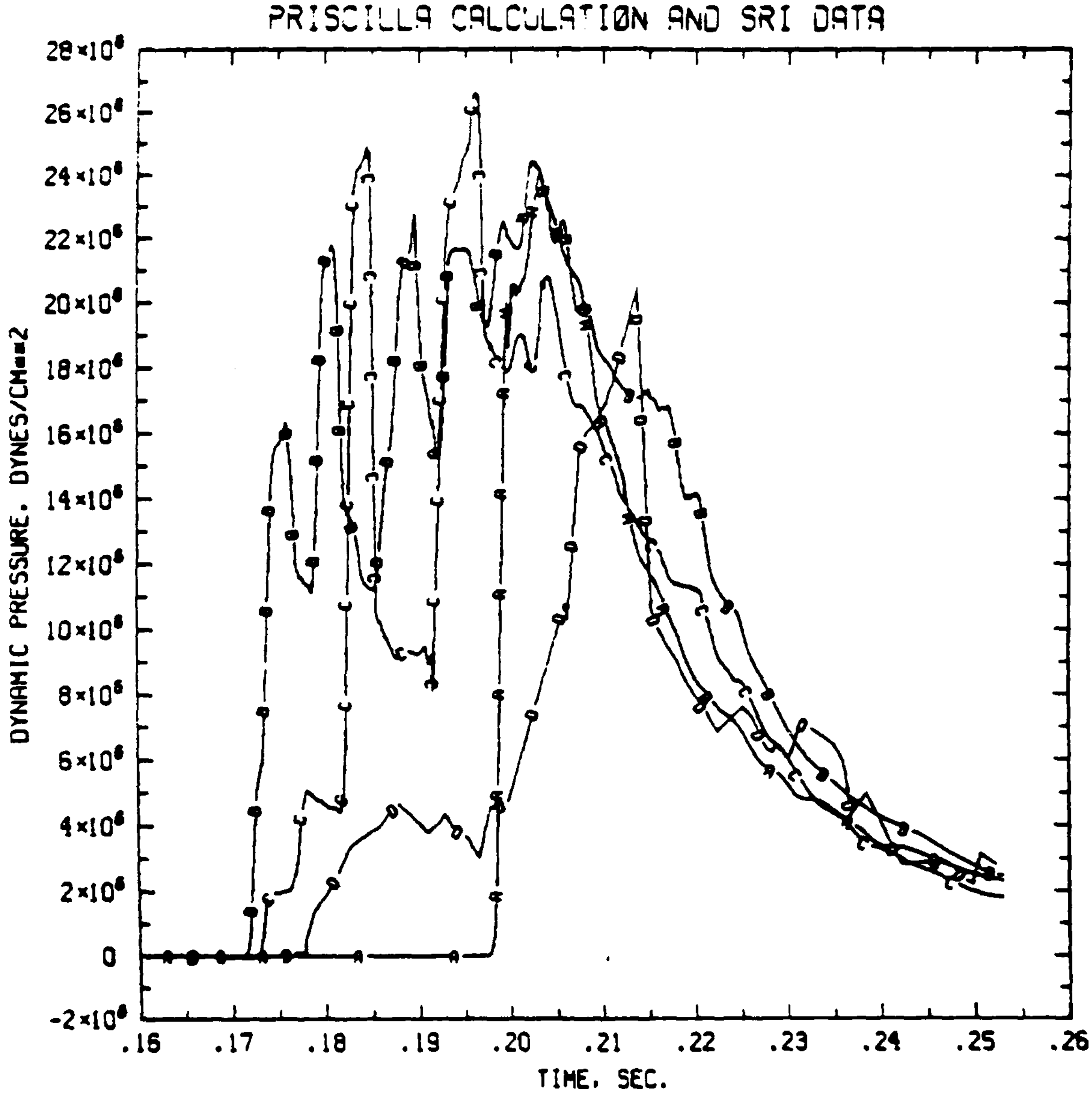

PRISCILLA CALCULATION AND SRI DATA
DYNAMIC PRESSURE, DYNES/CM**2
TIME, SEC.

Figure 46



XS, YS = 0.85000E+03 0.30000E+01 FT

Figure 47

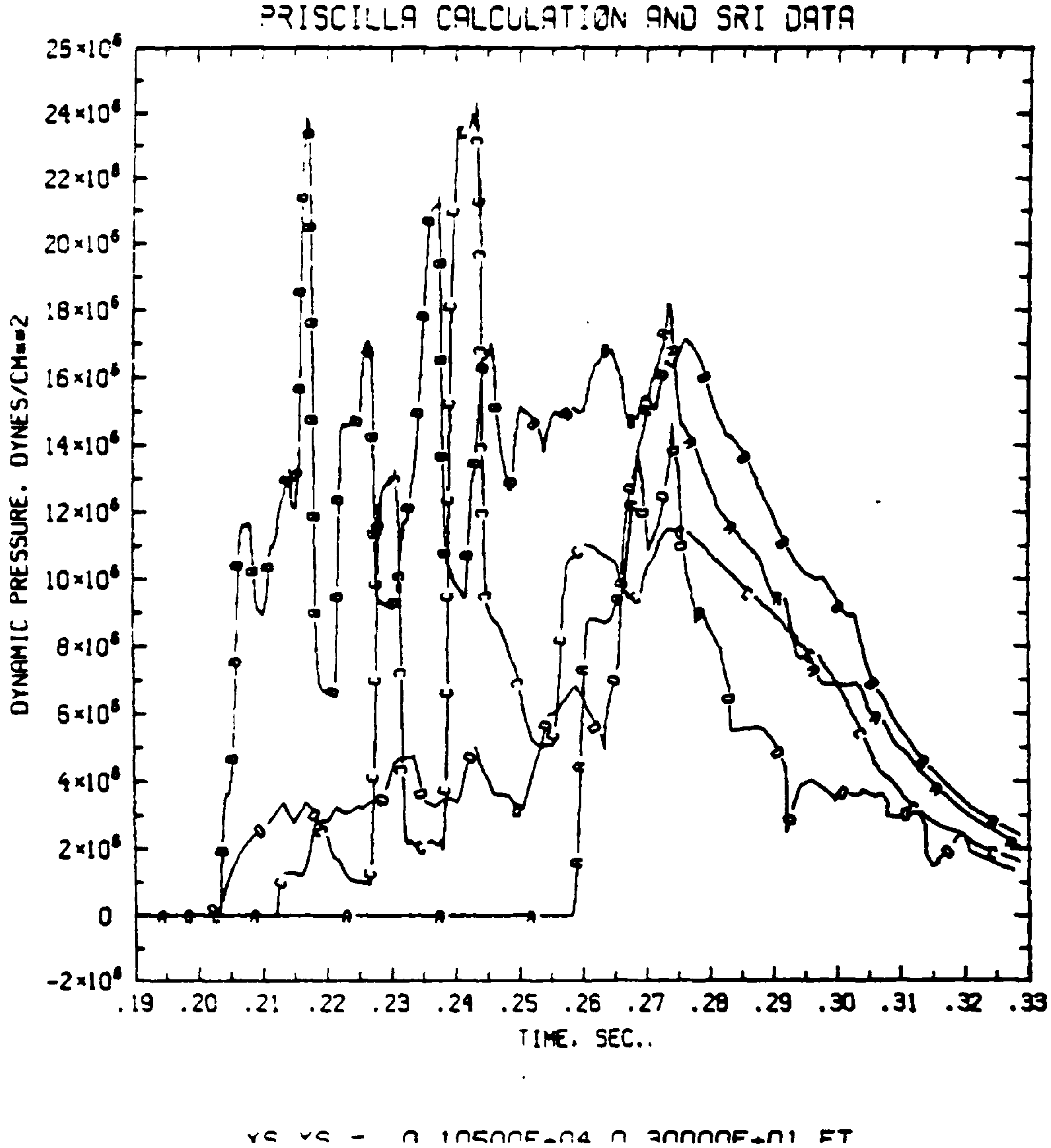
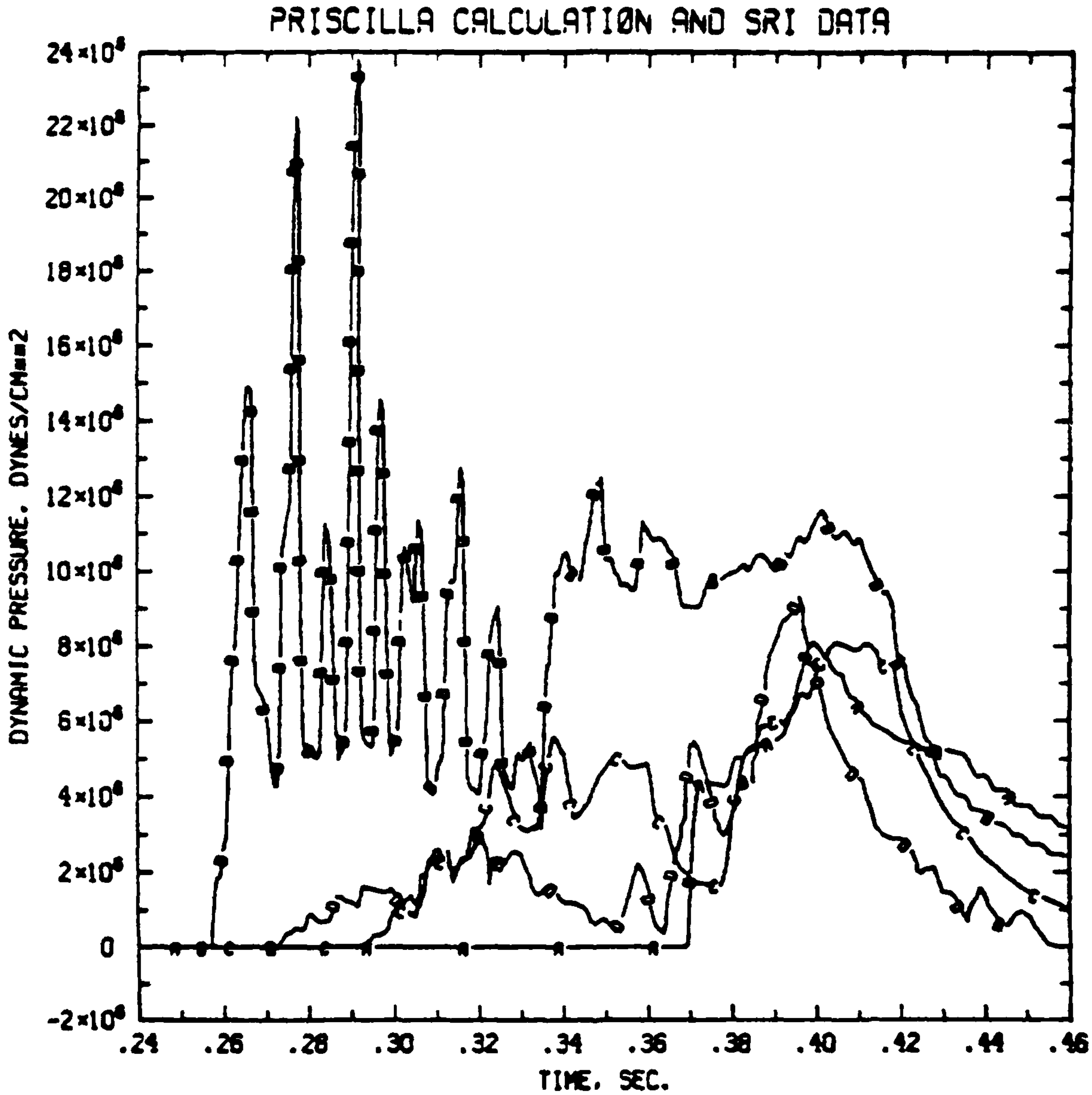

PRISCILLA CALCULATION AND SRI DATA
DYNAMIC PRESSURE, DYNES/CM**2
25×10⁶
24×10⁶
22×10⁶
20×10⁶
18×10⁶
16×10⁶
14×10⁶
12×10⁶
10×10⁶
8×10⁶
6×10⁶
4×10⁶
2×10⁶
0
-2×10⁶
.19 .20 .21 .22 .23 .24 .25 .26 .27 .28 .29 .30 .31 .32 .33
TIME, SEC.
XS, YS = 0.10500E+04 0.30000E+01 FT

Figure 48



XS,YS = 0.13500E+04 0.30000E+01 FT.

Figure 49

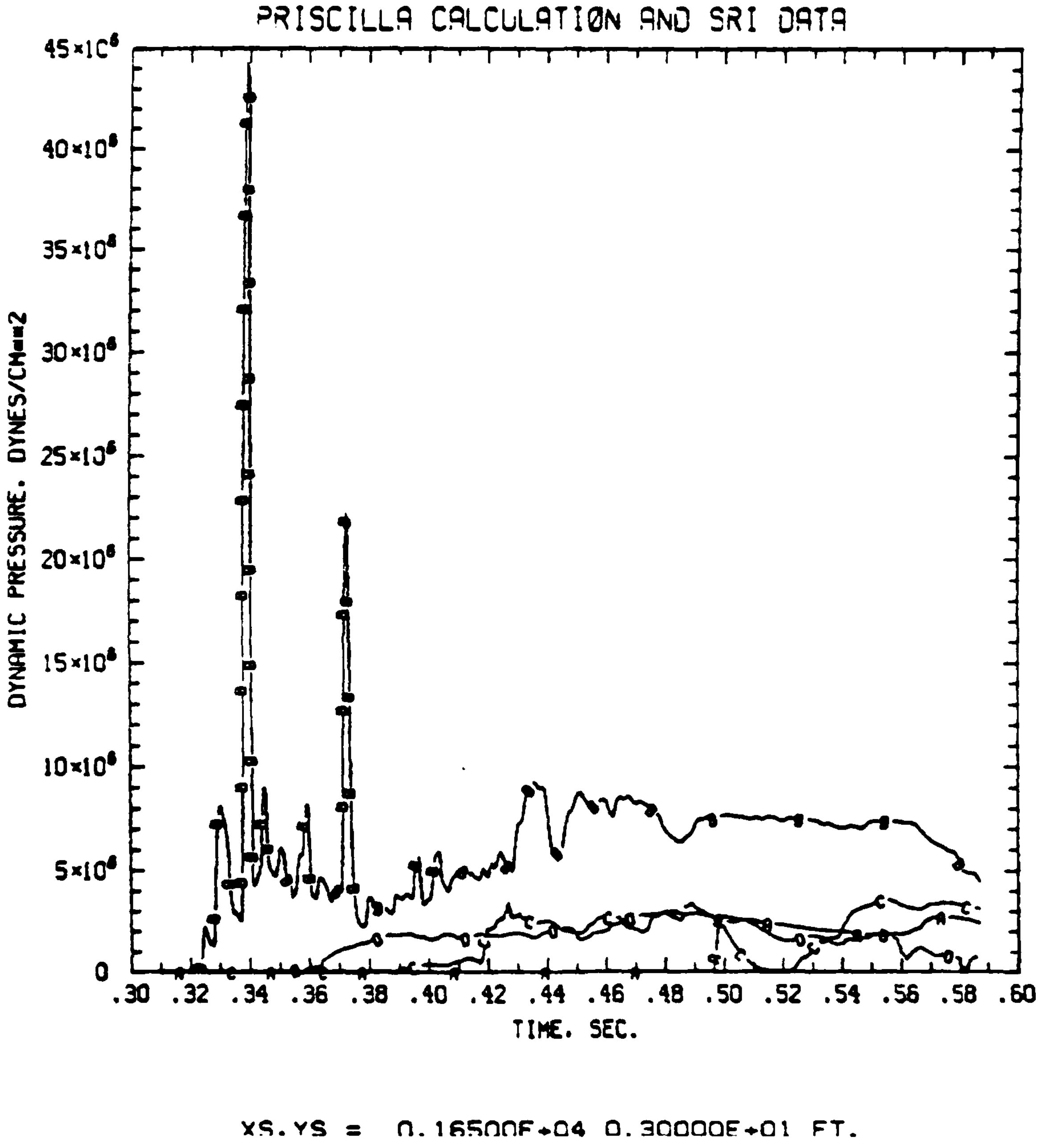
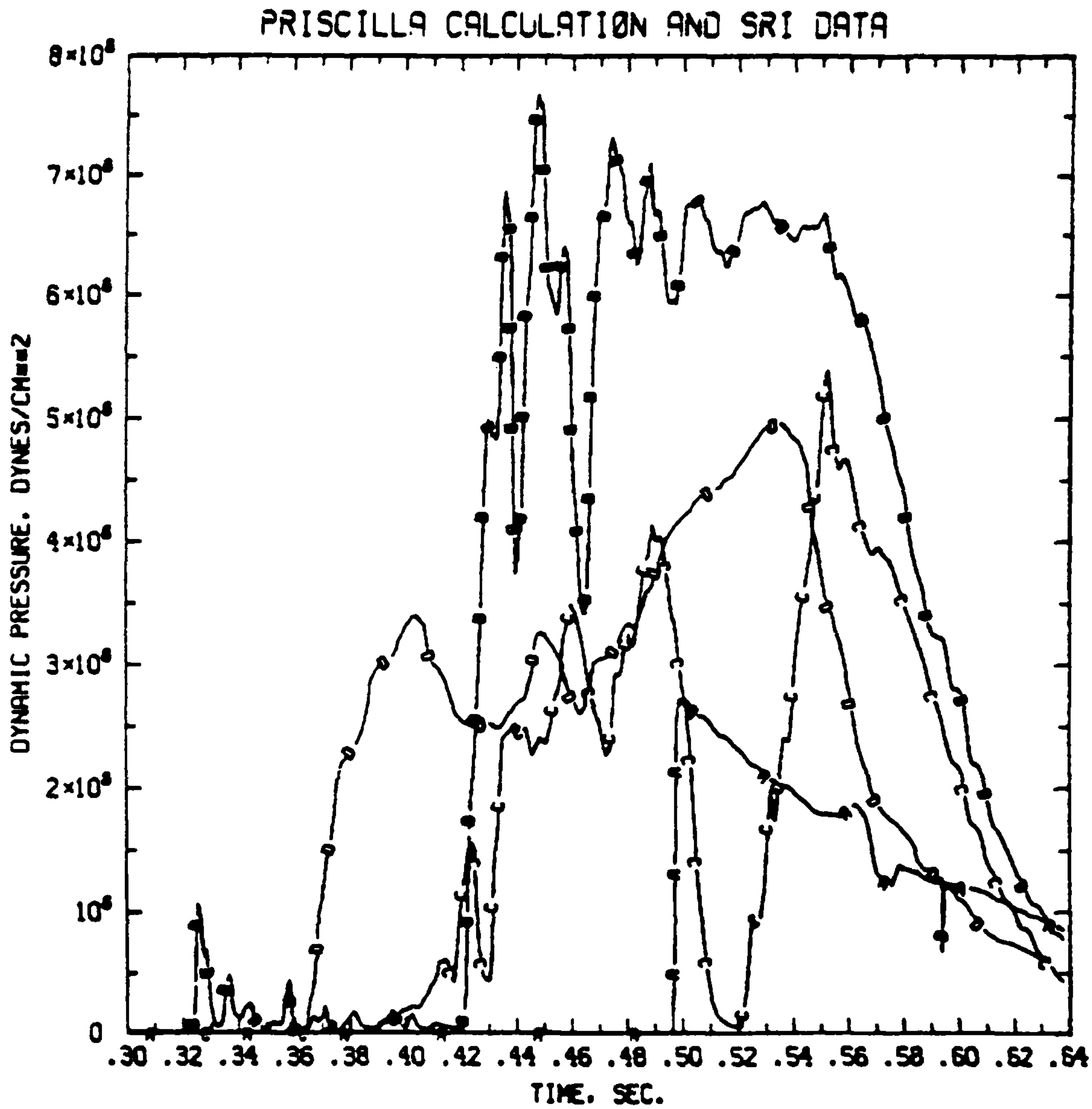

PRISCILLA CALCULATIØN AND SRI DATA
DYNAMIC PRESSURE, DYNES/CM**2
45×10⁶
40×10⁶
35×10⁶
30×10⁶
25×10⁶
20×10⁶
15×10⁶
10×10⁶
5×10⁶
0
.30 .32 .34 .36 .38 .40 .42 .44 .46 .48 .50 .52 .54 .56 .58 .60
TIME, SEC.
XS,YS = 0.16500E+04 0.30000E+01 FT.

Figure 50



XS, YS = 0.16500E+04 0.10000E+02 FT.

Figure 51

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